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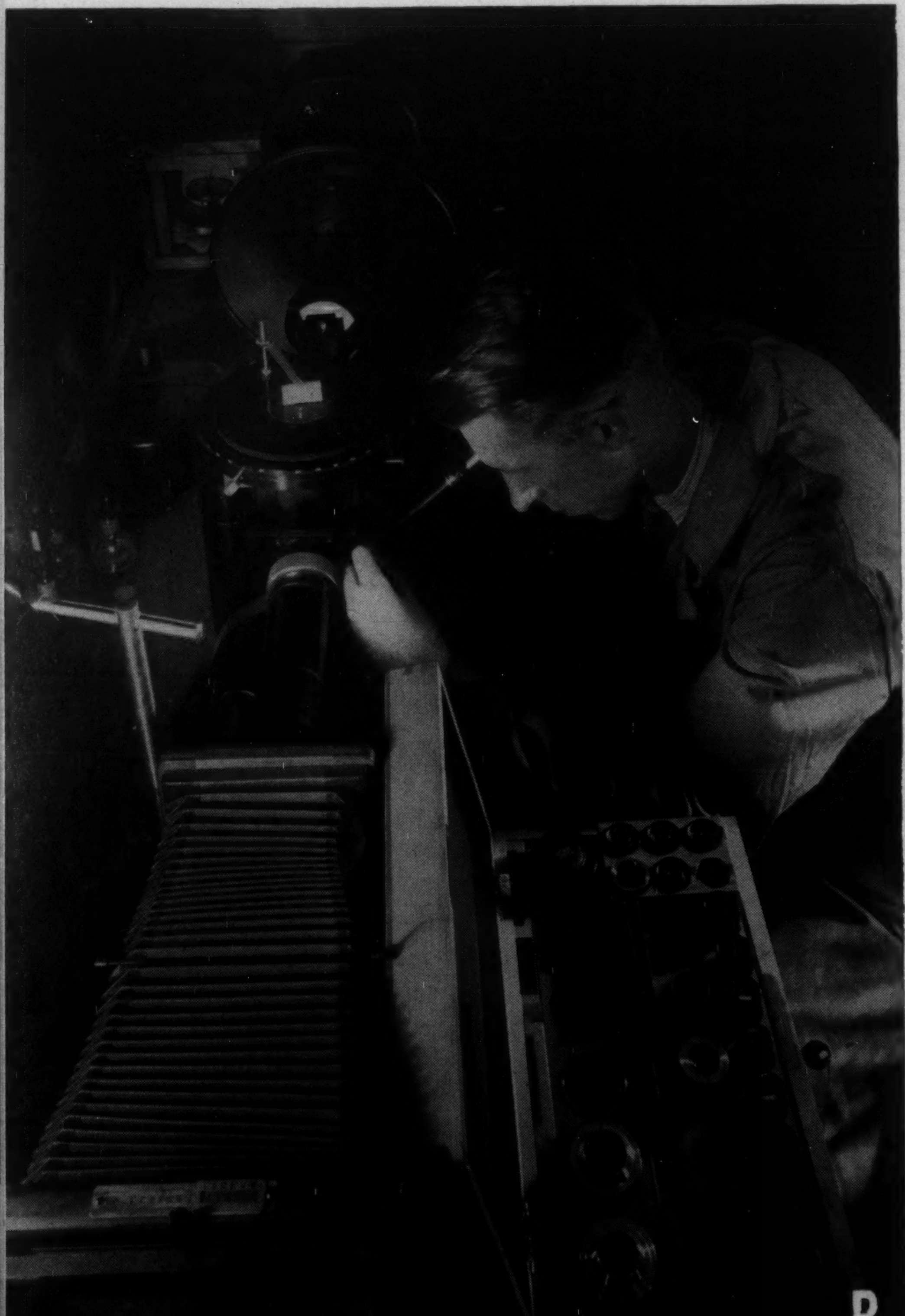

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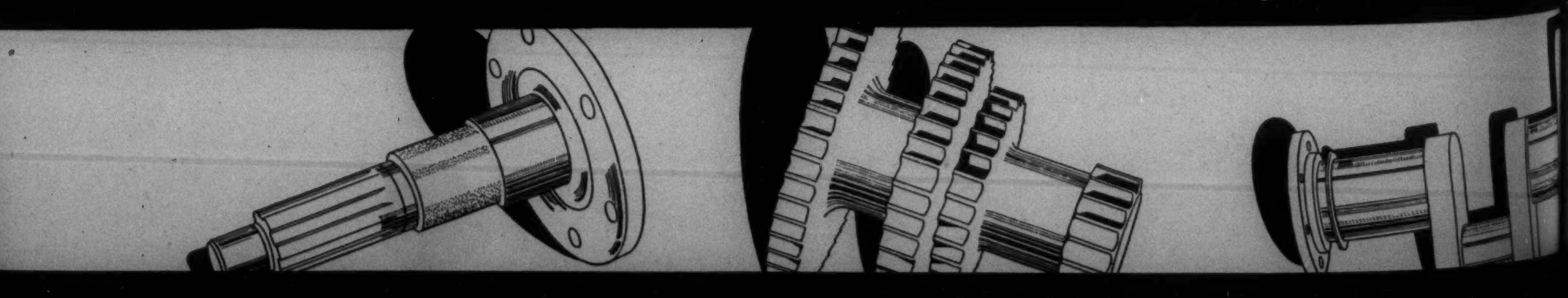


Electric Furnace Brazing by Kelvinator

by E. W. CUNNINGHAM

Industrial Heating Specialist
General Electric Co., Detroit

This is not the first article of its type to be published. The methods for furnace brazing with copper and its applicability for assembly of parts previously joined in more expensive and laborious ways have been described. Nevertheless we still see the older, wasteful methods in use by manufacturers who ought by this time to know that there is a better way. Despite the growth of furnace brazing, its rate of growth seems far slower than it ought to be. This article describes the methods in such detail that anyone with a problem at all similar can clearly see how the process could be applied to his own case. It would seem that a good many metallurgical engineers, who have already been vainly urging their managements to introduce furnace brazing on the work for which it is suited, will find added ammunition in this account.—The Editors.

WITH THE INTRODUCTION of the 1939 models, the Kelvinator Division of Nash-Kelvinator Corp., Detroit, incorporated with its manufacturing methods the use of electric-furnace brazing to fabricate parts used in their well-known hermetically-sealed refrigerator. In the beginning it was planned to use furnace brazing principally on three main parts, namely, the dome assembly, the condenser, and the muffler-and-head assembly. These parts are all used in the domestic unit which naturally represents the bulk of the Kelvinator business.

Since the process was introduced, however, many additional parts have been added to the list of those being furnace brazed. These parts include the following: Liquid receiver shell, high-side float assembly, suction tube, condenser-header assembly, valve assembly and accumulator assembly. Practically all of these new parts are incorporated in the commercial refrigeration unit which also runs into sizable quantities. Because of the space limitations, the parts described in detail below are the ones in the first group which are used only in the domestic unit.

Preparing Dome Assembly for Brazing

The dome assembly is shown in Fig. 1. At the left the dome is shown with its component parts, preparatory to assembly, and at the right is shown the complete furnace-brazed dome assembly. The complete unit is approximately 9¼ in. in diameter by 8¼ in. high, and weighs 9 lbs.

The dome A, is drawn from ⅛-in. hot-rolled stock, pierced with holes for the fittings and terminal bushings. As a preliminary step, the domes are thoroughly washed to remove the drawing compound used in their formation. Then they go to the assembly line where they are prepared for furnace brazing.

There is a total of 11 parts, assembled and copper-brazed to the dome. These are: Three motor-terminal bushings B, one discharge fitting C, one charge fitting D, four mounting legs E, and a silencer F. The charge fitting D is a subassembly made of two screw-machine parts brazed as a unit along with the dome assembly.

The individual terminal bushings and the charge and discharge fittings are screw-machine parts. They have flanges which fit snugly against the dome side, and tenons which fit into punched holes in the dome. The flanges have recessed edges to provide a positive location for copper-wire rings G that serve as the brazing metal. These rings are made from ordinary commercial copper wire 0.040 in. in diameter, which is wound into a helicoil on a motor-driven spindle. The helicoil is then cut through its length to make the individual rings.

The copper rings are first pressed into the recesses

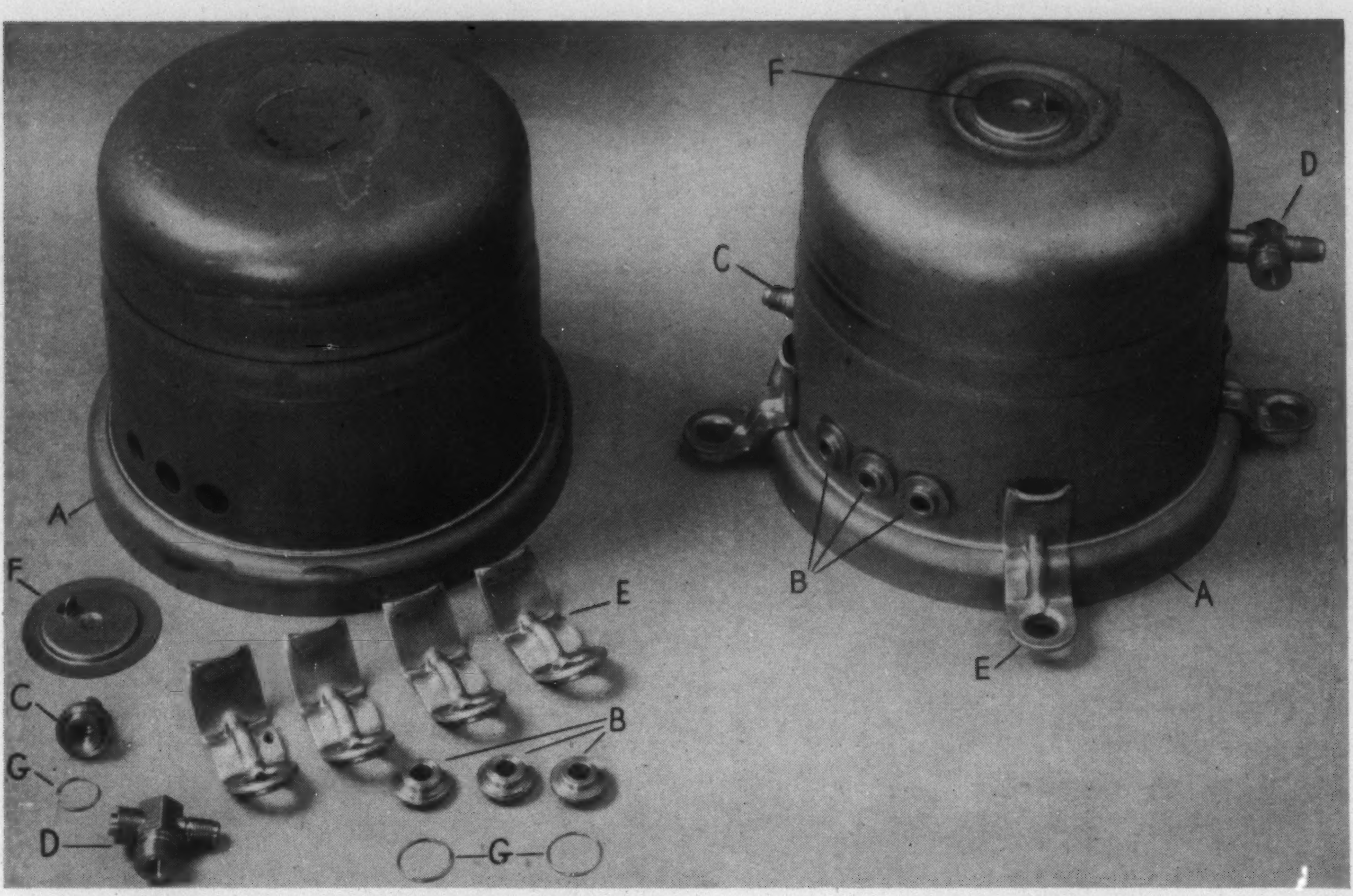


Fig. 1. Component parts for dome assembly (left) and copper-brazed dome assembly (right).

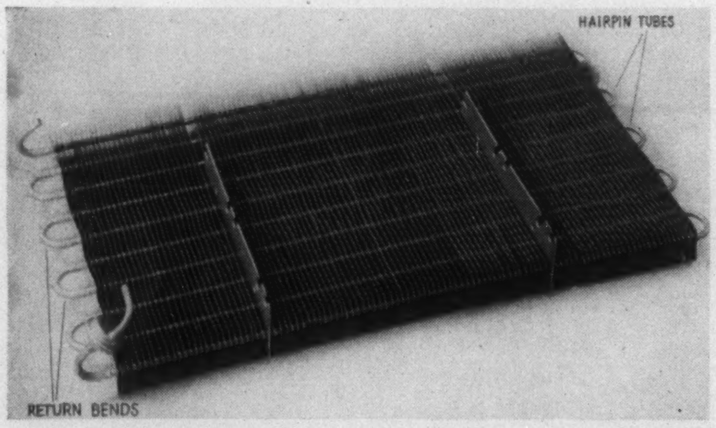


Fig. 2. Condenser assembly made of steel fins and steel tubing which has approximately 1050 joints copper-brazed in a single trip through the furnace.

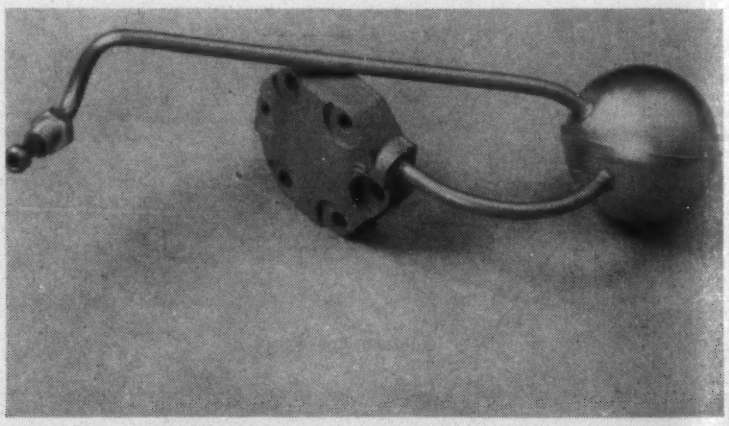


Fig. 3. Muffler-and-head assembly, made of steel stampings, steel tubing, steel screw-machine parts, and a permanent-mold iron casting. This assembly has 5 copper-brazed joints.

in the fittings and the fittings are then pressed into place on the dome. This method of assembly proves to be a simple way of applying the copper and at the same time assures that it will be adjacent to the joints. Thus, when the copper melts in the furnace, it will be drawn into the joints by capillary attraction. It has been found that if snug fits are provided during assembly of the parts, the resulting bonds will be uniformly tight and exceptionally strong.

To eliminate the possibility of the fittings and bushings dropping out or being displaced in handling, or while in the furnace before the bond is made, the parts are staked in position as they are pressed into the dome.

The mounting legs, after being formed and pierced, are spot welded to the dome to hold them in place; 12-gauge copper wires, 3/4 in. long, are inserted at the top of the legs into lips provided in the forming operation.

The silencer is a stamped cap which is simply placed in position on top of the dome and secured by a copper paste made from copper powder and equal parts of lacquer and thinner. The paste supplies sufficient copper to braze the cap to the dome.

(After the furnace-brazing operation, the silencer is filled with lead shot).

Final preparation of the dome assemblies for furnace brazing consists of setting six of them on a cast-alloy tray on a gravity conveyor immediately in front of the furnace, and applying the copper to the legs and the silencer, as described above. From here the assemblies travel through a continuous controlled-atmosphere furnace, where the copper melts, creeps into and throughout all joints by capillary attraction, forms alloys with the parent metal, then solidifies to make strong, tight bonds. The assemblies leave the furnace free of oxides and flux deposits, with clean, bright surfaces.

Dome Assembly As Previously Fabricated

The dome assemblies were previously fabricated by another method. As the domes were received from the vendor they were carefully washed to remove drawing compounds, then the charge and discharge fittings and the terminal bushings were projection welded in place. The four legs were secured by a double spot weld and the silencer was spot welded in position. After the assemblies were completed they received an acid pickle and an alkaline and hot-and-cold water wash. Following the pickling operation, the domes were wire brushed to remove the last traces of compound.

In the manufacturing of hermetically-sealed refrigerators, every precaution must be taken to assure clean, scale-free work. The slightest scale can easily contaminate the oil and refrigerant, resulting in wear and noise, or clogging of the mechanism. Since the introduction of electric-furnace brazing, all cleaning operations on the domes after assembly have been completely eliminated. The domes are washed prior to the assembly of the fittings to remove the drawing compound, but other than that the parts can be used just as received from the furnace. Quite naturally, the elimination of the elaborate cleaning precautions required has affected material savings in manufacturing cost.

Another large saving on the dome assembly is the elimination of a water test after the fittings have been mounted. Before electric-furnace brazing was employed, each dome was clamped shut with cover plates and subjected to high air pressures under water to check for leaks. The present system has proved itself so entirely reliable that it is no longer necessary to make this expensive test as leakers are practically non-existent.

Kelvinator estimates the savings in manufacturing cost of the dome assembly since the introduction of electric-furnace brazing, including all operations from the time the dome reaches the plant until it is ready to be assembled with its compressor, amount to approximately 35 per cent over the method first used.

Preparing Condensers for Furnace Brazing

The condenser shown in Fig. 2 is 12⅞ in. wide, 1¾ in. high, 23⅞ in. long, and weighs 9 lbs., 6 oz. It consists essentially of steel fins copper-brazed to hairpin sections of steel tubing to provide a natural convection system for removing heat from the refrigerating liquid.

The individual fins are 0.010 in. thick. They are sheared from coiled strip, 10 holes are punched, the corners are cut off, and the fins are slightly crimped, all at the rate of 400 fins a minute from a super-speed press. In the punching of the holes, short lips are left which provides additional surface for joining the fins to the steel tubing. After the fins have been sheared, they are assembled in a jig which lines up the holes to receive the tubing.

The tubing used in the condensers is the well-known Bundyweld furnace-brazed steel tubing made by the Bundy Tubing Co., Detroit. It is ¼-in. O.D., supplied in cut lengths which are formed into hairpin sections. In each end of the hairpins, there is inserted a steel leader with a tapered, hardened head. The hairpins are then forced by a hydraulic press into the nest of fins held by the jig. The tapered leaders are used to assure perfect alignment of the fins for the tubes and also to size the holes in the fins to fit the tubes.

After the tubes have been located, the assembly is placed on end and copper rings are dropped over each open-end tube. Return bends are then placed in position and forced on securely with an arbor press. The return bends are formed from ¼-in. O.D. Bundyweld tubing with the ends slightly expanded to fit over the condenser tubes.

Copper is applied to the condenser only at the return bends. In addition to the copper rings, copper paste is used at the joints to assure perfect bonds.

The Bundyweld tubing is made from copper-plated steel strip formed into a double-wall tube and passed through a continuous furnace where the two walls are securely brazed together. This operation leaves just enough copper on the tubing to supply the requirements for bonding the fins to the tubes, and thereby simplifies the preparation of the condensers.

A strainer made from two steel stampings and a Monel screen is brazed together and bonded to the condenser simultaneously with the furnace-brazing of the condenser assembly. Copper paste is painted around the seam of the strainer housing but care is exercised here to prevent an excess of copper collecting in the Monel screen. If molten copper gets on the screen, it might chew holes in it. Altogether there are approximately 1050 furnace-brazed joints in the condenser, which aggregates about 70 lineal feet of bonding in each assembly.

Final preparation of the condensers for furnace

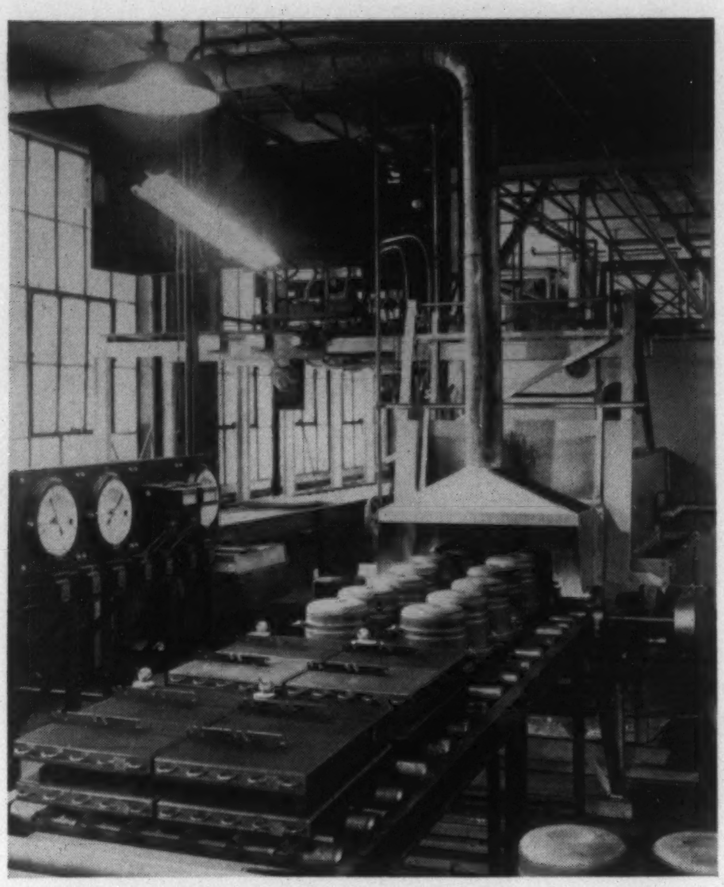


Fig. 4. Charging end of the G-E roller-hearth conveyor-type, copper-brazing furnace at the Kelvinator plant in Detroit showing condenser and dome assemblies ready to enter the furnace on trays. A driven-roller conveyor carries the trays through the furnace.

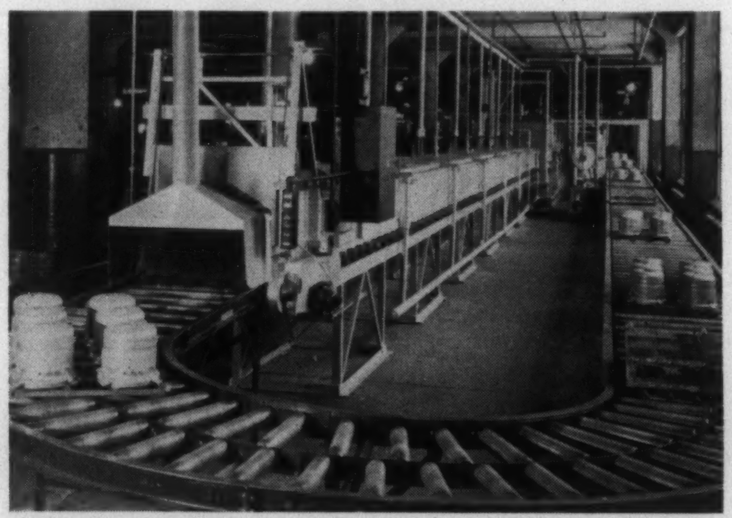


Fig. 5. Discharge end of roller-hearth furnace showing trayload of dome assemblies (left) automatically leaving cooling chamber and returning on roll table to be unloaded at charging end of furnace. The automatic charging and discharging arrangement of this furnace is a unique feature.

brazing consists of setting four of them on a light-weight fabricated tray, Fig. 6, two wide and two high, with light-weight spacers separating the two tiers.

Condenser as Originally Manufactured

It is difficult to compare the former process of manufacturing the condensers with the present one, from a cost standpoint, because of the radical change in design brought about partially through the use of the furnace-brazing method and partially because of certain fundamental changes in the refrigerator design. This year the Kelvinator refrigerator is cooled by natural convection rather than forced convection, and this change in itself necessitates a condenser approximately three times as large as the one formerly used.

The condensers used before the introduction of electric-furnace brazing were made from a formed length of continuous-steel tubing with a uniquely-formed continuous-copper fin pressed into place between the loops. The assemblies were dipped in solder to secure the fins to the tubing and assure uniform and consistent heat transfer.

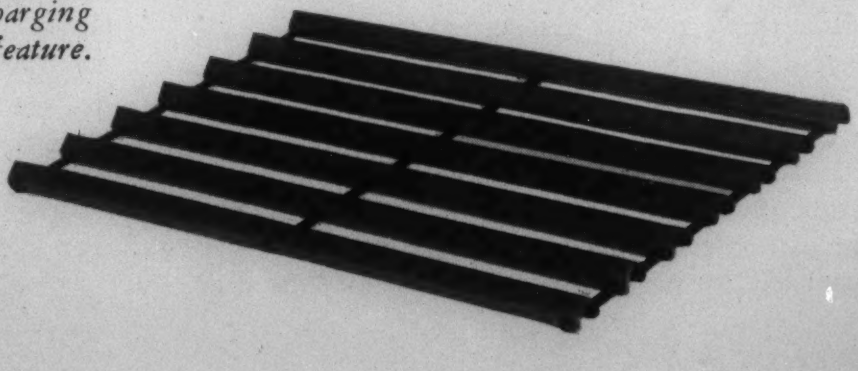
It is evident, however, that a considerable saving has been effected through this change in design, as an old-type condenser of the new, large size, with its copper fins and solder-dipped joints, would be considerably more expensive than the present furnace-brazed, steel-fin condenser.

Preparing Muffler-and-Head Assembly

The muffler-and-head assembly shown in Fig. 3 consists primarily of a ball muffler made from two stampings pressed together, and a permanent mold cast iron head. The two parts are connected with a piece of 1/4-in. O.D. Bundyweld steel tubing. The assembly is about 10 in. long by 3 in. wide by 3 in. high, and weighs about 1 lb.

The electric-furnace brazing process is utilized to bond the two stampings together, to braze the connecting tubing to the bodies, and to join a ferrule on the end of the open tube—a total of 5 joints. The two stampings are simply pressed together prior to the furnace-brazing operation. It is unnecessary to resort to spot welding to hold them together, as is the case with certain refrigerator floats of similar

Fig. 6. Light-weight tray made of sheet-alloy channels with tie rods and spacers, representative of the type used in the Kelvinator furnace.



construction that are not so well vented. After drawing the shells a hole is punched in each half section to take the connecting tubes. A small copper ring is pressed over the end of each connecting tube so that it will be in contact with the shell adjacent to the joint after the tube is pressed in place. An 0.040-in. ring is placed around the seam between the half shells.

Sometimes cast-iron is quite difficult to copper braze, partially because the oxides are not completely reduced by the furnace atmosphere. As a consequence, the copper has difficulty in wetting the surface. The Kelvinator division has overcome this inherent difficulty in brazing the cast-iron head, however, by using an homogeneous permanent-mold casting and employing as the brazing metal not only copper wire but also some copper paste with a small amount of flux added. The copper wire fits snugly against the head and is held in place by the paste. The great reducing property of the flux is sufficient to clean up the surface and allow the copper to wet the iron.

Before the ferrule is pressed on, a cylindrical stainless-steel shim and a connection fitting are assembled on the open-end tube, the purpose of the shim being to keep the fitting free to turn by preventing it from becoming brazed to the tube. Then the ferrule, which is copper-plated to provide the brazing metal, is pressed on the end of the tube.

Final preparation of the muffler-and-head assemblies for furnace brazing consists of setting 16 of them on a light-weight grid or screen, Fig. 7, which rests on one of the light-weight trays shown in Fig. 6. The muffler ball and cast head rest directly on the grid, and the cast head serves as a support for the long open-end tube which, after furnace brazing, is reformed to fit the general assembly. These sub-assemblies, as the others, come from the furnace bright and clean, with uniform tightness at all joints.

Comparison with Muffler-and-Head Assembly As Originally Manufactured

The electric-furnace brazing of the muffler-and-head assembly has materially simplified methods and construction. The halves of the muffler ball were originally tin-plated inside and outside to resist corrosion. The main seam on the muffler was seam welded. Connecting tubes were torch-brazed in place. This left oxide and flux deposits that had to be removed, to prevent particles from getting into the mechanism and to prevent corrosion by the flux. Two fittings were necessary to make the union between the cast head and the muffler.

With the furnace-brazing method now employed, the tin-plating is omitted, all 5 joints are brazed in a single trip through the furnace, and since the surfaces are clean and bright subsequent cleaning operations are not required. A single connecting tube between the head and the muffler now replaces the former connecting tubes and fittings. Rejections for leaks have been reduced appreciably. And in addition to these benefits which are, obviously, accompanied by a sizeable cost reduction, the company has greater confidence in the reliability of joints now made.

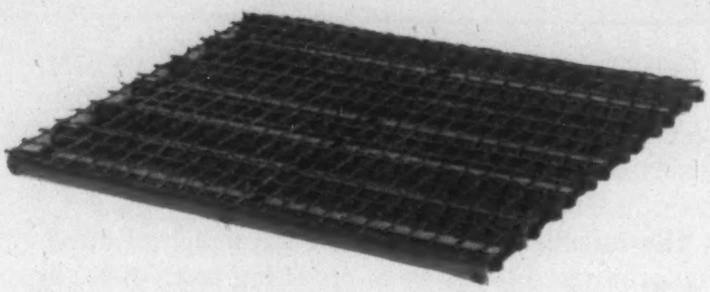


Fig. 7. Small sub-assemblies, such as the muffler-and-head assembly shown in Fig. 3, rest on supporting grids tied to the trays.

Brazing Furnace Described

The furnace used for this application is of the roller-hearth conveyor-type of one of the latest designs (Fig. 4). From the standpoint of production, it is the largest brazing furnace installation in the country.

The furnace consists essentially of an insulated heating chamber to which is attached a water-jacketed cooling chamber. It has a roller conveyor throughout its entire length. The rolls are provided with sprockets and are driven by a roller chain which is completely enclosed and sealed in a compartment on the side of the furnace. The conveyor speed is adjustable over a 6 to 1 range.

An unusual feature of construction not ordinarily used in brazing furnaces is the automatic charging and discharging arrangement. After a tray is loaded and the copper is applied to the sub-assemblies, it is pushed along the roller conveyor at the charging end by the operator, to a station in front of the furnace door. The automatic charging device, which is in readiness, is controlled by means of an electric eye located outside the furnace and a flag switch inside the vestibule. As soon as the last tray has moved in sufficiently to allow room for another tray, the door is opened automatically and a separate drive starts at high speed to carry the cold tray into the vestibule. When the tray hits the flag switch, power is withdrawn from and stops the auxiliary drive, and the door is automatically closed. The entire operation from opening to closing of the door requires only 5 secs. At the discharge end, when a tray is in position to be removed it hits the limit switch which opens the door, and starts an auxiliary drive which discharges the tray at high speed (Fig. 5). Then the door closes. The time required for this operation is only 3 secs. The tray runs around a 180-deg. turn by gravity and is then carried by a driven conveyor back to the front of the furnace, where it arrives at a convenient working height. At this point the trays are unloaded and returned to the charging-conveyor table by the furnace operator. The brazed parts are loaded on an overhead conveyor which carries them to the assembly line.

The automatic feature has the advantage of effecting a considerable saving in operating cost. Also, by keeping the doors closed practically all the time, it conserves the protective atmosphere and assures work of the highest quality from the standpoint of brightness.

The furnace is rated 320 kw. and has sufficient capacity to heat 2600 lbs. gross per hr. to 2050 deg. F. The heating units, which are made of heavy nickel-chromium ribbon formed in sinuous loops, are divided into three separately-controlled circuits in the length. The units are located in the roof and on the side walls both above and below the rolls. This construction assures uniform heating and at the same time allows surplus copper to drip on the furnace bottom without touching the units.

The door opening of the furnace is 28 in. wide by 13 in. high. The heating chamber is 17 ft. long inside and the cooling chamber is 70 ft. long. The overall length of the furnace, less end conveyors, is approximately 100 ft.

The reducing atmosphere for the furnace consists of the products of partial combustion of natural gas, with moisture partly removed, supplied by an atmosphere-gas converter. This gas mixture has approximately the following analysis:

	Per Cent
CO_2	5.0
Illuminants	0.0
O_2	0.0
CO	11.0
H_2	17.0
CH_4	2.0
N_2	65.0
	100.0

This type of gas is quite suitable for electric-furnace brazing, and is used almost universally for such work. Its unit cost is but a fraction of that of the fuel gas (natural gas) consumed.

Brazing Trays Described

The use of the roller-hearth furnace for brazing applications introduced a difficult problem of tray design. Trays for this application must be capable of carrying relatively heavy loads, must be light in weight, and still provide satisfactory life even when subjected to the high temperatures used in the copper-brazing process. Cast-alloy trays of several designs have been used, but as a general rule have proved unsatisfactory because of their excessive weight and tendency to warp and distort. Corrugated sheet-alloy trays have also been used, and although their light weight has favored the operating economy, the life has not been entirely satisfactory. The solution to the tray problem appears to be the channel-type tray shown in Fig. 6. This tray is made up of individual channels formed from sheet alloy, tied together with alloy rods. The channels are separated by alloy-sleeve spacers which fit over the tie rods.

This construction allows for expansion and contraction of individual members without distortion of the tray. It gives an exceptionally strong tray for the weight, and has demonstrated in several furnaces that its life is entirely satisfactory. The durability of the tray is undoubtedly explained by the fact that the freedom to move avoids setting up strains in the individual members.

At the Kelvinator Division the channel-type tray is used for the condensers and for the muffler-and-head assembly, as well as for several other parts not described in this article. For the small parts ribbon-mesh supporting grids are employed, which rest on the channels (Fig. 7).

The dome assemblies are loaded on a tray similar in construction to the one described above, except that cast I-section rails are substituted for the channels. The cast tray, however, has the same advantage of being free to move in the furnace without setting up strains in the individual members.

Summary

The use of electric-furnace brazing for fabricating parts used in the refrigeration industry has many accepted advantages. Cleanliness is a necessity in this type of work, and the parts as delivered from the brazing furnace are clean almost beyond improvement. Scale is completely eliminated and even the discoloration marks of the spot welds used to tack the parts together are removed in the reducing atmosphere of the furnace. Another "must" in the design and manufacture of a hermetically-sealed unit is tight joints that will not come loose in service. The furnace-brazing process not only provides joints that are tight and strong, but the method is so reliable that expensive tests and checks are not required in order to be positive of this fact.

Direct and substantial savings are effected by combining in one equipment and in one process the assembly of many parts. The savings can be attributed to elimination of cleaning operations, less inspection, reduced weight of parts, reduced number of rejects, fewer repairs and reruns in the factory, and reduced servicing costs. Evidence that the Kelvinator Division of Nash-Kelvinator Corp. has been experiencing the benefits is shown in the fact that this company has been constantly increasing its use of the furnace-brazing process since the furnace was installed.

Tinning Copper and Brass by Immersion

by JOHN D. SULLIVAN and A. E. PAVLISH

Battelle Memorial Institute, Columbus, Ohio

THIS ARTICLE REPORTS an immersion process and a new tin bath that can be used to apply coatings to copper and brass, including intricate shapes, at ordinary room temperature. The coating gives protection to tubing against "green water" and has many other applications, some of which are mentioned later in this paper.

Metallic coatings are applied to various metals and alloys to obtain specific properties such as appearance and resistance to corrosion. Application by hot-dipping, electroplating and spraying are well known to metallurgists and electrochemists, but the immersion method involving plating by simple chemical replacement without the use of electric current is less known. On the other hand, immersion processes are extremely valuable for certain applications, and coatings can be applied to intricate shapes and to a variety of sizes that can not be handled readily by other processes. Immersion coats are ordinarily quite thin; so their application is limited to uses not requiring extremely heavy coatings.

In the past the application of immersion coating of metals has been quite limited. Some copper-coated iron and steel has been made in this manner, but the production has been of no great importance. Iron and steel articles, such as pins, eyelets, buttons, etc., have been coated with tin by immersion processes that depend on the electrolytic action of the metal being coated. Ordinarily the articles are in contact with metallic zinc which serves to furnish an internal source of electric current.

The compositions of a few typical baths that have been used for the deposition of tin by immersion follow:

1. A saturated solution of cream of tartar (potassium acid tartrate) containing 4 to 30 grams of stannous chloride per liter and operated at boiling temperature.[1]

2. A bath containing 20 to 30 grams of ammonium alum and 1 to 2 grams of anhydrous stannous chloride per liter. The solution must be used at boiling temperature.[2]

3. An alkaline bath containing 15.0 grams of stannous chloride, 18.7 grams of sodium hydroxide, and 7.5 grams of sodium cyanide per liter, operating at boiling temperature.[2]

Immersion coating of copper and brass articles has been practiced to a limited extent, particularly on pins, screws, etc. Baths similar to those described above have been used, and in all cases a hot solution has been employed, and frequently a contact metal has been used.

There are many applications of copper and brass that require a coating such as tin either for protective purposes, or for appearance. Copper and brass are used widely in plumbing, but in many cases trouble is encountered with so-called "green water" resulting from dissolution of copper from pipes, tubes, and fixtures. It is reported that trouble results if the content of copper exceeds about 5 parts per million, although color is detectable at concentrations as low as 2 parts per million. Green stains are accentuated by soaps because of the formation of insoluble colored copper compounds; so the trouble is particularly noticeable in bathrooms. Often, the trouble disappears when a non-metallic coating, for example, of insoluble calcium salts, forms on the inside of pipes after a few weeks' use. A protective coating to retard temporarily dissolution of the copper until the non-metallic coating is built up is highly desirable. Attempts have been made to overcome the difficulty by coating the inside of pipes and tubes by hot-tinning, but the method is expensive, cumbersome and frequently the coating is not satisfactory in quality. Electroplating the inside of tubes and pipes is impractical because there is no effective way of getting the current into the inside. Past immersion coating baths have not been considered feasible because of the hot solutions required and the contact metals necessary.

The Process

The process comprises applying a tin coating to copper or brass by a simple immersion process.[3] The article is thoroughly cleaned to remove grease and dirt, and preferably pickled, although this step is not essential, immersed in a solution consisting essentially of sodium stannite and sodium cyanide, washed and dried. The better the condition of the metal surface before immersion, the better will be the appearance of the coating. Either hard or soft copper or brass can be coated. The process, likewise, is applicable to copper-coated or brass-coated articles.

The chemistry of the process is described in greater detail later in this article, but in general it is merely the stoichiometric replacement of tin in the bath by copper dissolving from the metal. Naturally, when the copper becomes coated completely the action stops and no additional coating is built up. This necessarily results in a relatively thin coating, but one which nevertheless is complete and gives a good degree of protection. In a complex cyanide-stannite bath, the concentration of free Sn^{++} is low; so the coating is uniform and adherent. The appearance also is pleasing.

An outstanding feature of the process is that coating is effected readily by immersion in a cold bath. The concentration of tin in the bath is high enough so that vigorous stirring is unnecessary, and complex shapes, for example, the inside of coiled tubing, can be coated. This may be done by circulating the solution, but in many cases filling the tube or pipe with solution, letting it stand for the required time, draining and washing is sufficient. This is made possible by virtue of the use of a cold bath. Obviously, tank immersion is practicable, and expensive containers are unnecessary For example, wood or steel tanks are satisfactory.

Character of Coating

As previously stated, a uniform adherent coating is obtained. The thickness depends on the time of immersion. Data are given in the Table for a specific bath containing 50.0 g. per l. NaCN, 5.0 g. per l. $SnCl_2 \cdot 2H_2O$, and 5.6 g. per l. NaOH.

The nature of the coating is shown in Fig. 1, which is a photomicrograph of tin-coated copper. Copper was electroplated on the surface before polishing to serve as a backing material for the thin tin coating.

Table 1. Relationship of Tin Deposited on Copper to Period of Immersion in the Bath; solution contained 50 g. per l. NaCN, 5.0 g. per l. $SnCl_2 \cdot 2H_2O$, 5.6 g. per l. NaOH.

Period of Immersion in Bath	Tin Deposited	
	Thickness, inch	Weight, g./sq. dm.
5 min.	0.000004	0.006
15 min.	0.000006	0.012
30 min.	0.000009	0.017
1 hr.	0.000014	0.026
2 hrs.	0.000021	0.040
24 hrs.	0.00014	0.262

Heating the Coating

If a tin-coated article is heated slightly above the melting point of tin, the latter alloys, at least in part, with the copper. This is illustrated in Fig. 2, which shows a specimen immersed for 24 hrs. and heated at 250 deg. C. for 30 mins. This surface may be given an additional immersion treatment so that there are three distinct layers: Sn, the diffused layer of Cu + Sn, and Cu. This is illustrated by the photomicrograph in Fig. 3.

Fig. 1. Immersion coating of tin on copper. 100X.

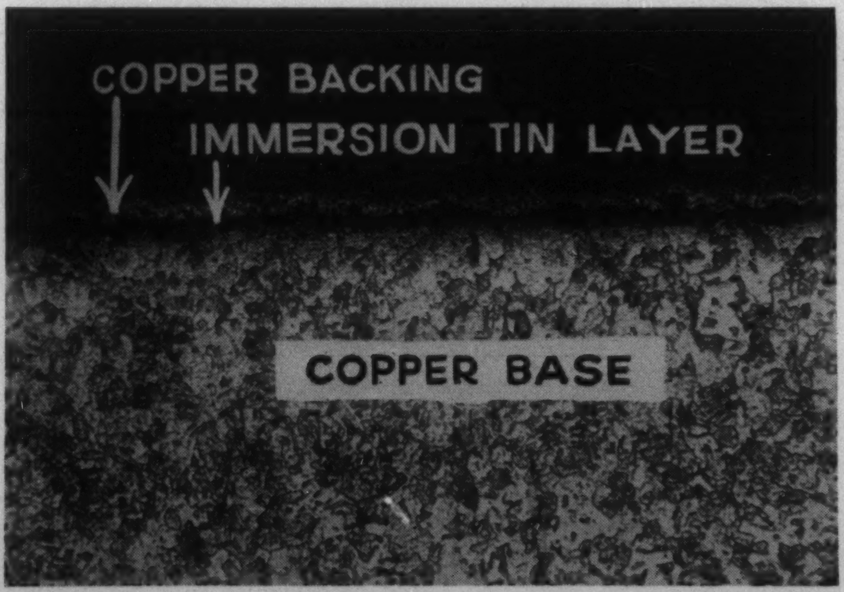
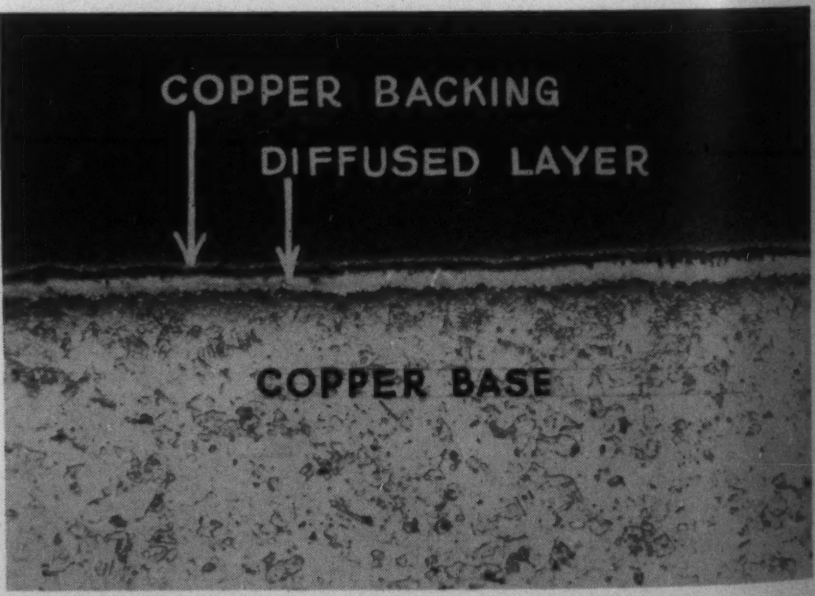


Fig. 2. Immersion coating, heated. 100X.



Copper and a wide variety of brasses and bronzes can be treated by the process. It is applicable to the ordinary red and yellow brasses, commercial Cu-Sn alloys, and brasses and bronzes containing low percentages of aluminum and other alloying ingredients. It is not applicable to high nickel-copper alloys such as Monel.

Application to "Green Water" Problem

Extensive tests have shown that excellent protection is given to copper and brass tubing against dissolution of copper which leads to "green water" troubles. Tests showed that the most severe attack on uncoated pipe or tubing was caused by distilled water saturated with carbon dioxide, CO_2.

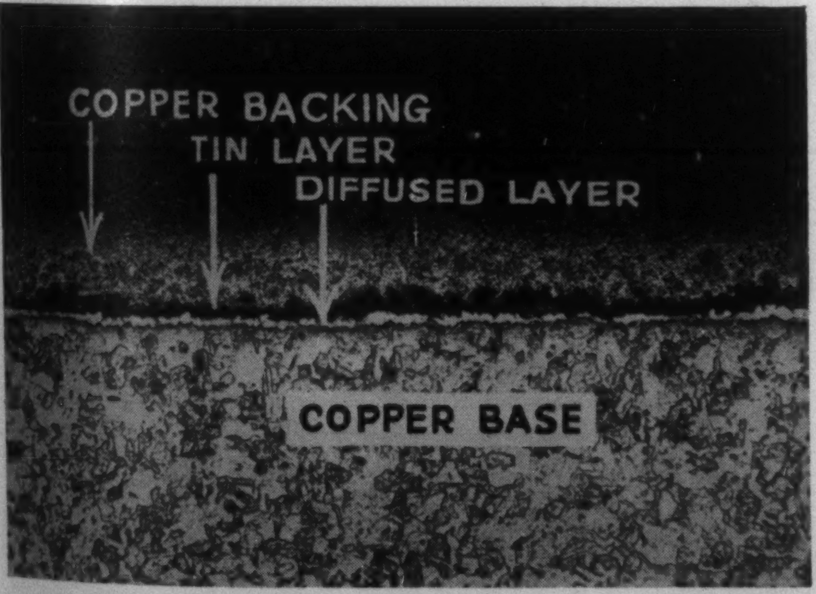
Fig. 4 gives data on an unprotected and 2 tin-coated 1-inch diameter copper tubes. Tube No. 1 was the uncoated or control trial, tubes Nos. 2 and 3 were immersed for 1 and 2 hrs., respectively, in a bath at room temperature containing 50.0 g. per l. NaCN, 5.0 g. per l $SnCl_2 \cdot 2H_2O$, and 5.6 g. per l. NaOH. At each sampling all the water was drained from the tube and a new supply of distilled water saturated with CO_2 was added. The points on the curves in Fig. 4 show the time the solutions were in contact since the last draining, and each point, therefore, indicates the amount of copper dissolved since the solution was last changed. Tubes coated for 30 mins., heated, and again immersed for 30 mins., also gave adequate protection as the copper did not increase above 2 p.p.m. during the first 40 days and at the end of the test did not exceed about 3 p.p.m.

Chemical Considerations of the Process

As stated previously the process is essentially one of chemical replacement at ordinary temperatures without use of contact metals. No external current is used. Metallurgists are familiar, from their Freshman chemistry, with the so-called electromotive series of the elements. Physical chemists, however, consider the electromotive series in the light of the electro potentials of the elements.

In the usual form of the electromotive series Sn^{++} is above Cu^{++}; so addition of metallic tin, Sn°, to a solution containing Cu^{++} will result in precipitation of metallic copper, Cu°, from solution with a corresponding stoichiometric dissolution of Sn metal. Addition of Cu° to a solution containing Sn^{++} will not result in precipitation of Sn°. The process here described is, therefore, an apparent contradiction to the ordinary electromotive series. It has been shown, however, that the electro potential of Cu^{++} is higher than Sn^{++} in a NaOH-NaCN solution of the type used in this work; so metallic copper, Cu°, goes into solution and Sn^{++} is converted by the replacement to tin metal, Sn°, which plates on the copper article. The process, therefore, is based on replacement in a complex solution with an electromotive series of elements that differs from the one customarily considered, which in fact is based on electro potentials in acid solutions.

Fig. 3. Immersion coating, heated; again immersed. 100X.



Concentrations of Baths That Can be Used

Tin: With NaCN constant at 50.0 g. per l. the concentration of tin as sodium stannite was varied from 0.5 to 17.0 g. per l. Good bright deposits were obtained in all cases. This and other work indicated that the concentration of tin in the bath is not critical, but that it must be in the stannous condition. The concentration, however, should be high enough so that too frequent replenishment with sodium stannite or $SnCl_2$ is unnecessary. In most work the authors standardized at about 2.0 to 3.0 g. per l. tin as sodium stannite; *i.e.,* 3.3 to 5.0 g. per l. Na_2SnO_2.

NaCN: Baths were prepared with the sodium stannite held constant at 4.4 g. per l. and with the sodium cyanide varying from 5 to 150 g. per l. The effectiveness of the coating from the various baths was determined by immersing cleaned copper specimens in the baths for 5, 10, 30 and 60 mins., and testing the tin coating produced. The coated specimens were examined for appearance and completeness of tin coating, and they were also subjected to a hydrogen sulphide corrosion test, which comprised exposing the tin-coated specimens for one hour in a covered desiccator saturated with water vapor and containing hydrogen sulphide. The results are shown graphically in Fig. 5.

It is obvious, of course, that the hydrogen sulphide test is a severe one, and that for many purposes the appearance test is sufficient. The data show, how-

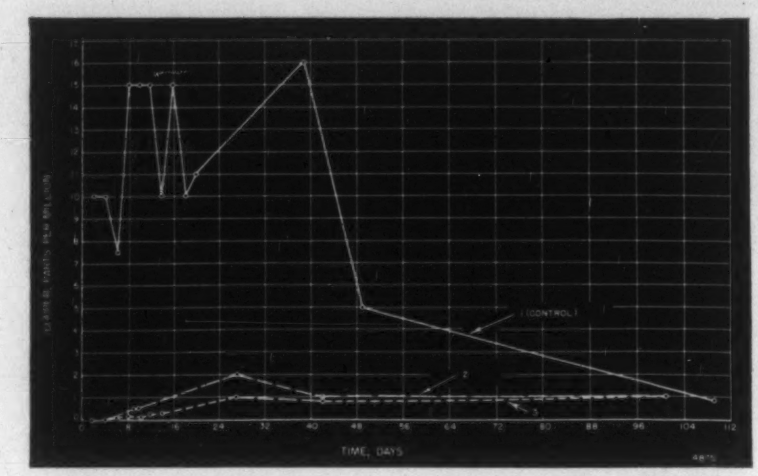


Fig. 4. Corrosion tests on coated and uncoated copper.

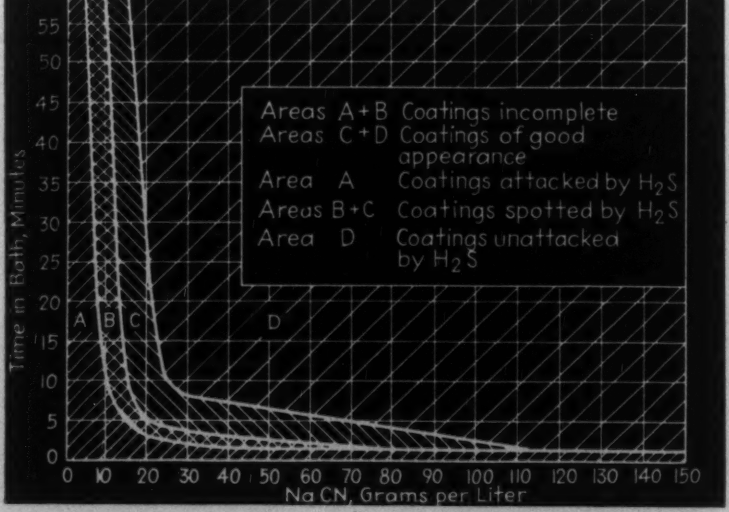
ever, that high cyanide concentrations are desirable, and that by employing them, the time required to obtain a satisfactory coating is noticeably decreased. For best all-around service the concentration preferably should exceed 25 g. per l. NaCN, and 50 g. per l. is recommended.

Stability of Baths

No particular attention is required to keep the bath in working order. Periodic titrations should be made to insure that the NaCN and stannous tin concentrations are high enough. Stannous tin is slowly oxidized in stannite-cyanide solutions to the stannic condition, and in this form it will not coat, but fairly high concentrations of stannic tin can be tolerated with no ill effect, provided the bath contains stannous tin. Addition of as much as 200 g. per l. $Na_2SnO_3 \cdot 3H_2O$ did no apparent damage. As the stannous tin is depleted, the bath can be replenished by adding a stannous salt, for example, sodium stannite or stannous chloride.

Sodium cyanide, likewise, decomposes in baths to form carbonate and some cyanogen. This rate, however, is no greater than in cyanide electroplating solutions. A bath containing 51.0 g. per l. NaCN after standing open in the air for 16 days had decreased only to 48.7 g. per l., and one with 25.0 decreased only to 23.5.

Fig. 5. Showing effect of NaCN concentration on character of tin coating. Bath: 5.0 g. per l. $SnCl_2 \cdot 2H_2O$, 5.6 g. per l. NaOH. Room temperature.



Copper dissolved from the copper or brass will not cause trouble in normal operations. Addition of as much as 50 g. per l. of either $CuSO_4 \cdot 5H_2O$ or Cu_2Cl_2 had no ill effect on a bath.

The sodium stannite-sodium cyanide is easily prepared. Sodium stannite is produced by the reaction of a stannous salt, for example, stannous chloride, with sodium hydroxide according to this equation:

$$SnCl_2 + 4\ NaOH \rightarrow Na_2SnO_2 + 2\ NaCl$$

Sodium hydroxide is added slowly and with agitation to an aqueous solution of stannous chloride. After adding the sodium cyanide and diluting to the required volume, the bath is ready for use.

Applications

Applications were mentioned previously and specific data given on protecting plumbing from "green water" formation. The process, however, has wide application and can find use in any place where a relatively thin coating of tin on copper or brass is required. Only a few possible uses will be mentioned. It would appear that the protection is adequate for tinning copper wire to be used with rubber type of insulation. The tin not only adds resistance to corrosion, but also gives a coating conducive to soldering.

Novelty articles, fixtures, etc., can be given satisfactory coatings. One of the authors used an ash tray coated in this manner for over 2 yrs., and at the end of that time the finish was still satisfactory. The tray was easily cleaned.

Sheet iron or steel can be copper-coated and the resultant product then can be tin-coated by the immersion process described in this paper. It has been shown that the product can be soldered, and that certain types of can containers can be made successfully from the product. There are decided possibilities of making a relatively cheap tinplate, with satisfactory properties for many applications.

Costs

The total cost, of course, is a problem that is individual with each plant or shop and depends on size, degree of mechanization, and other factors. The chemical cost for continuous operations of coating copper or brass, including drag-out losses but not cleaning or pickling costs, is estimated on sheets to be on the order of 10 cents per 100 sq. ft.

References

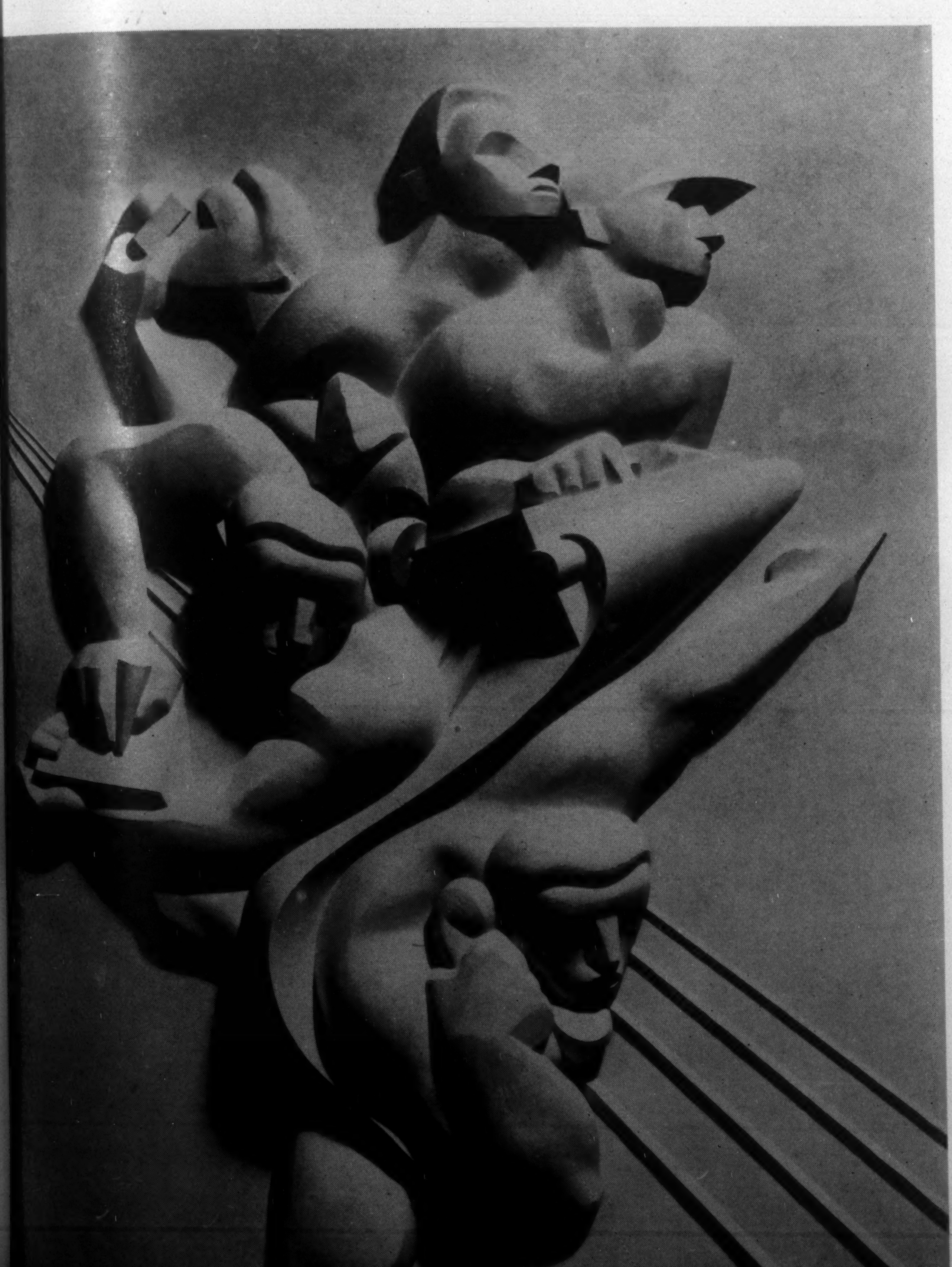
[1] Mantell, C. R. *Tin. A.C.S. Monograph,* Chemical Catalog Co., Inc., 1929, p. 168.

[2] MacFayden, H. "Coloring of Metals," *Monthly Review of American Electroplaters Society, 22,* p. 13, (November, 1935).

[3] U. S. Patent No. 2,159,510.

A Notable Plaque in Stainless Steel

The plaster model from which the plaque was cast in nine sections. The casting is a duplicate of this.



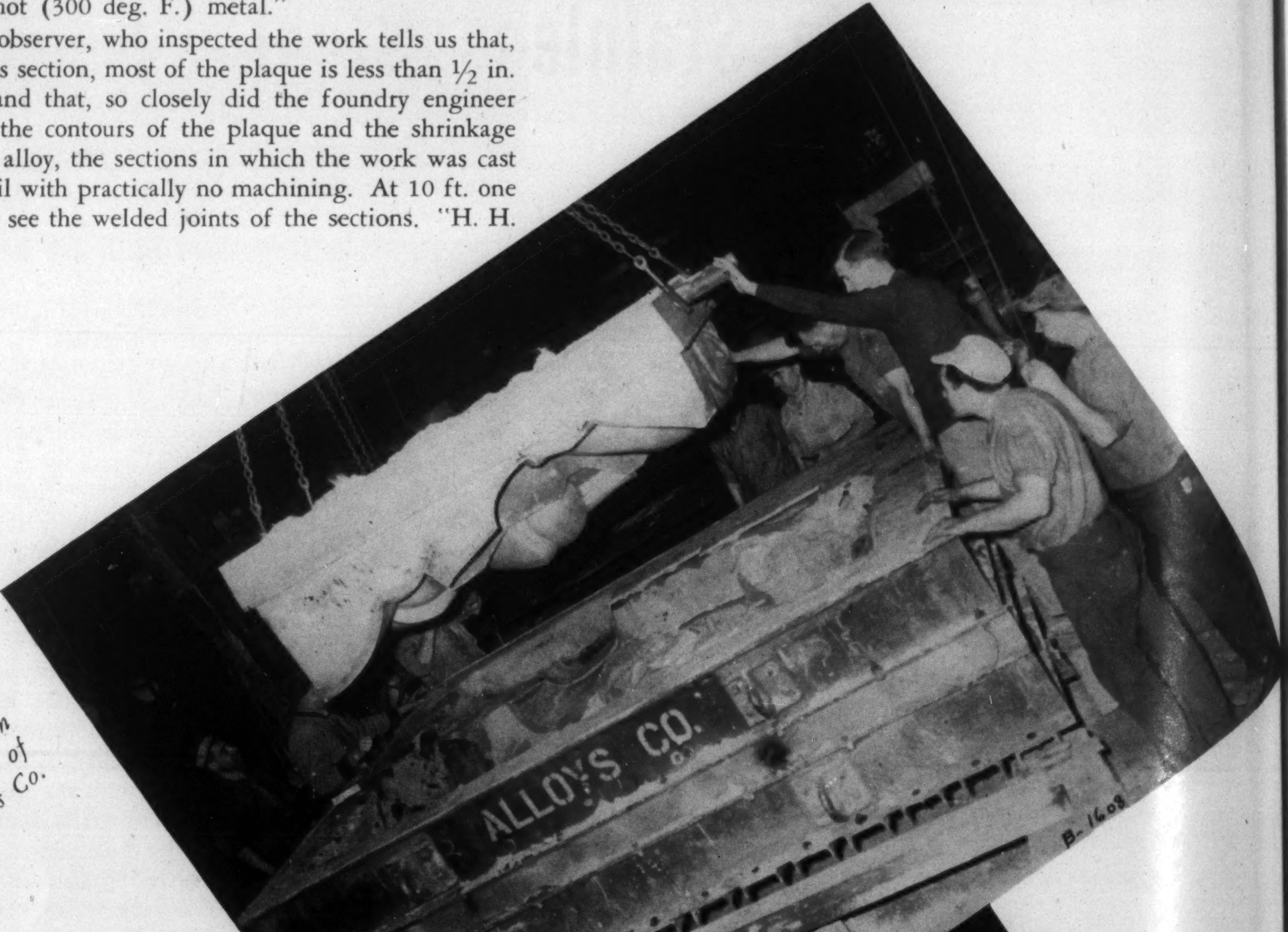
Over the main entrance of the Associated Press Building in Rockefeller Center in New York, there has been erected a huge panel of stainless steel which is said to be the largest metal bas-relief ever cast. In it are 10 tons of this alloy and it is pointed to as the first piece of heroic sculpture ever cast in this art medium.

Designed as a symbol of "News," the panel depicts the heads and torsos of 5 men. Four of them are working with tools of modern journalism — the teletype, wire photo, camera, and telephone. The fifth one carries the pad and pencil. The designer is Isamu Noguchi, a Japanese-American artist and winner of the national competition for the A. P. building plaque.

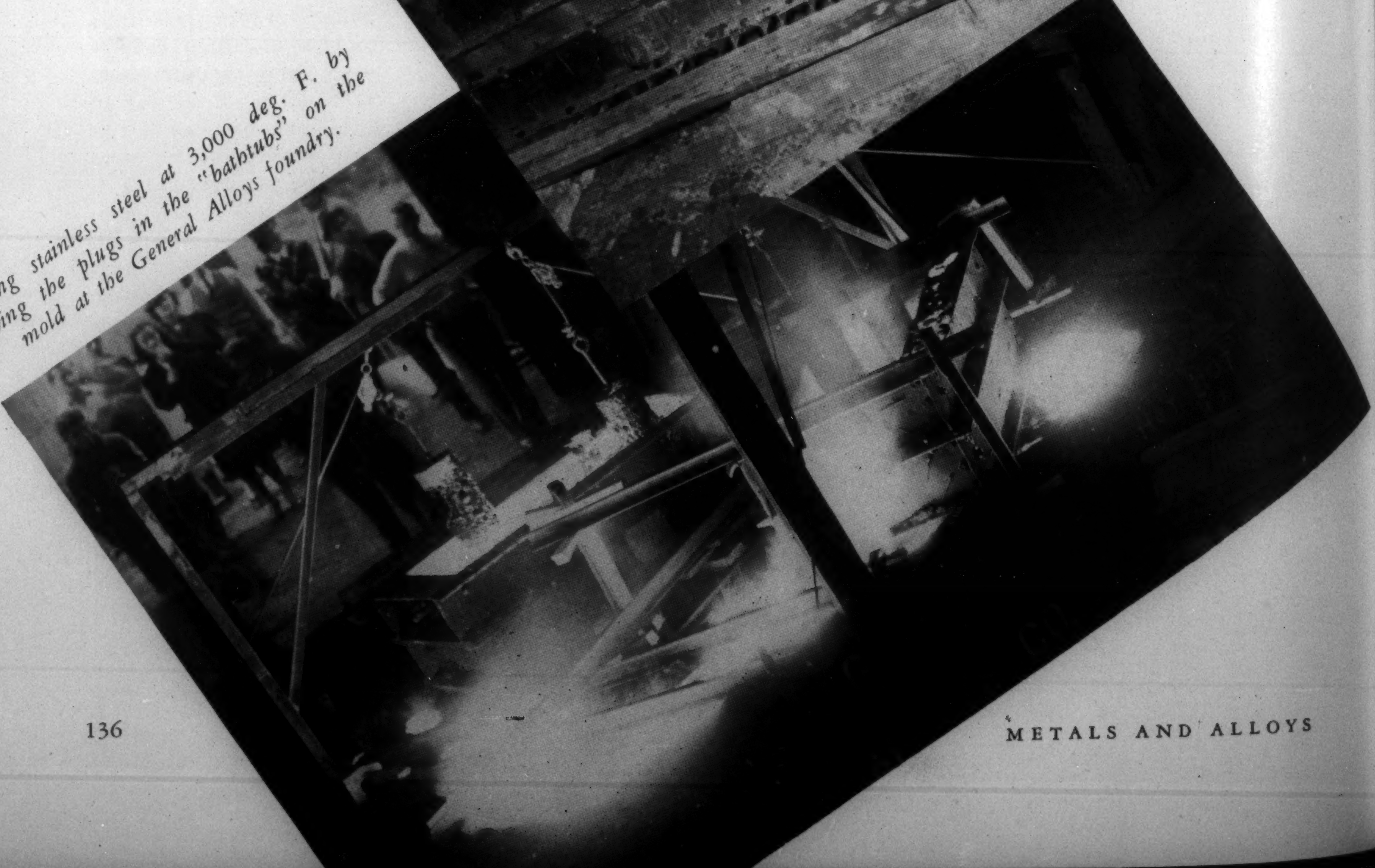
Its production is regarded as an achievement in metallurgical engineering and in foundry practice. It was produced in the Boston foundry of the General Alloys Co. For months the sculptor and the workers in the foundry, under the direction of H. H. Harris, president of the company, have been struggling with the experimental problem of casting the huge panel which measures about 17 by 22 ft. It was cast in 9 sections, obtained by cutting up the plaster model as made by Mr. Noguchi.

One of the chief technical problems of casting each of these sections was that it would destroy any ordinary sand mold. How this problem was solved is stated by Mr. Harris: "We rigged up a couple of 'bathtub' reservoirs on top of our mold, and then built a whole network of runners that would carry the metal quickly and evenly over the whole surface. The 'bathtubs' were fitted with big plugs that could be pulled out simultaneously, and in one explosive second the casting was completed. The action was so fast that there was not time for the sand to be disturbed by the white-hot (300 deg. F.) metal."

An observer, who inspected the work tells us that, in cross section, most of the plaque is less than ½ in. thick and that, so closely did the foundry engineer figure the contours of the plaque and the shrinkage of the alloy, the sections in which the work was cast dovetail with practically no machining. At 10 ft. one cannot see the welded joints of the sections. "H. H. Harris, to whom the Rockefellers entrusted the job, after all others who were consulted pronounced it impossible, has surely accomplished the metallurgical and architectural achievement of the decade."—E.F.C.



Drawing one of the nine sections of the model, used as a pattern, from the mold in the Boston foundry of the General Alloys Co.



Pouring stainless steel at 3,000 deg. F. by pulling the plugs in the "bathtubs" on the mold at the General Alloys foundry.

Modern Rhodium Plating

BY JOSEPH B. KUSHNER

Plating Consultant, 192 Broadway, New York

TEN YEARS AGO rhodium was practically a chemical curiosity. Today this precious metal of the platinum family is finding wider and wider uses in the field of electrodeposition. The lustiest newcomer to the roster of electroplated metals, it has in the short space of a decade come out of the laboratory beaker and into the commercial plating tank.

Uses of Rhodium

Rhodium plating is used by the manufacturer of diamond rings who finds that a deposit of bright rhodium over a white gold setting greatly enhances the beauty of the stones that are set in it. Its particular blue white tinge by an optical effect, no doubt multiple reflection, seems to give diamonds added brilliance and increased size.

The silversmith employs rhodium plating to protect silverware from tarnishing in air. The process is sometimes called "Rhodanizing."

Manufacturing novelty jewelers use rhodium plating to produce the effect of precious metal on costume and dress ornaments at comparatively low costs.

Rhodium plating is utilized by watch and instrument makers as well as optical frame fabricators to prevent corrosion of metal parts that come in contact with the body.

Electrodeposited rhodium is employed as a first surface of metallic mirrors and reflectors for search lights. This recently acquired popularity and wide spread application of rhodium in the electroplating and finishing industries springs from the interesting properties of the metal itself.

Properties of Rhodium

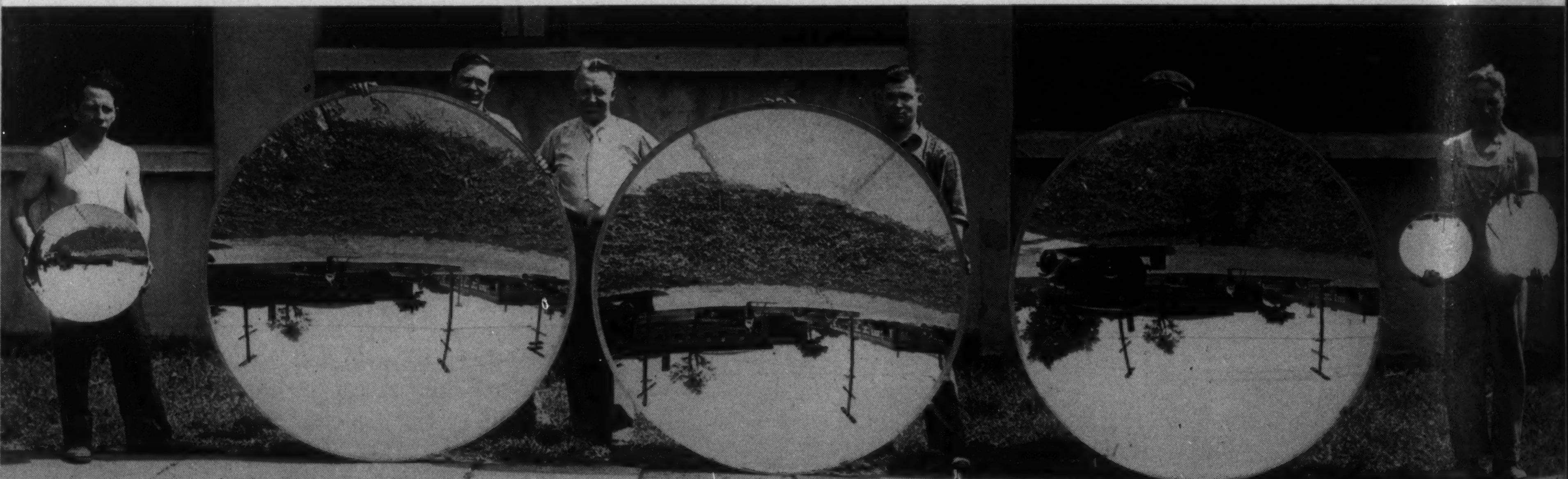
Rhodium is a bluish white member of the platinum group of elements. It has a high white light reflectivity (about 78; platinum is 65; silver, 91). It does not corrode or tarnish, being barely attacked by such powerful chemical reagents as aqua regia. It is fairly heavy (specific gravity 12.1) and has an extremely high melting point (1950° C.). Last but not least, its hardness when electrodeposited is close to that of plated chromium. ("Electrodeposited chromium has an average Brinell hardness of 670, rhodium about 600.")*

These properties early attracted the attention of practical electrochemists who were trying to find the answer to a problem put to them by the jewelry houses. For a long time manufacturing jewelers had been looking for a covering metal with which to whiten and brighten their white golds. White golds, alloys of gold, silver and nickel, were cheaper than platinum-iridium alloys but unfortunately had slight yellowish casts which detracted from, rather than enhanced the beauty of diamonds set in them. They wanted something as good as platinum or better to cover the off-color-white precious metal alloys.

Platinum plating solutions failed to give the desired effect as deposits from solutions available at the time were dark and dull in appearance. Tin, strange as it seems, was tried, but invariably caused a blackening or discoloration wherever worn adjacent to the human body. Chromium, then coming into popularity, was also experimented with but found disfavor as it swung the color pendulum too far in the other direction, towards the blue end of the spectrum.

Sources of the Metal

Since 1804, when the metal was discovered by Wollaston, rhodium had been won by a tedious refining process almost exclusively from Russian platinum concentrates in which it existed in low percentages (about 2% on the average). This made the cost of the rhodium so high as to preclude its application to electrodeposition. In fact, outside of its rather insignificant use as an element of the platinum-rhodium thermocouple for high temperature measurement, it was in every sense of the word,



Bottom: Employees of the Bart Laboratories holding huge rhodium plated searchlight reflectors for inspection.

Top: To demonstrate the rhodium plated reflector's accuracy, paper is ignited at the focal point of the parabolic mirror by heat from the sun's rays.

a museum metal. Then in the 1920's a commercial source of rhodium was discovered in the refining sludges of certain Canadian nickel ores. Almost immediately the price of the metal dropped sufficiently to permit laboratory trials of its electroplating possibilities.

Early Solutions Were Alkaline

The first rhodium plating solutions tried were alkaline in nature. It was reasoned by the chemists that, since the noble metals, gold, silver and platinum gave best deposits from alkaline solutions, rhodium ought to do likewise. An exception to the rule, it turned out that alkaline rhodium baths gave poor deposits, dark in color and low in throwing power. On further investigation, it was discovered that some of the Werner complex compounds of rhodium were stable in acid solution and gave excellent, brilliant deposits. In consequence, rhodium electrolytes of low pH were explored, subsequently resulting in the adoption of the sulphuric and phosphoric acid solutions of these complexes for practical rhodium deposition. The typical modern rhodium plating bath of today contains about 2 grams of metal as a complex compound plus 20 to 40 milliliters of conc. H_2SO_4 or phosphoric acid, dissolved in a liter of water. This type of bath, while operating at a rather low cathode efficiency, gives beautiful, bright deposits of rhodium.

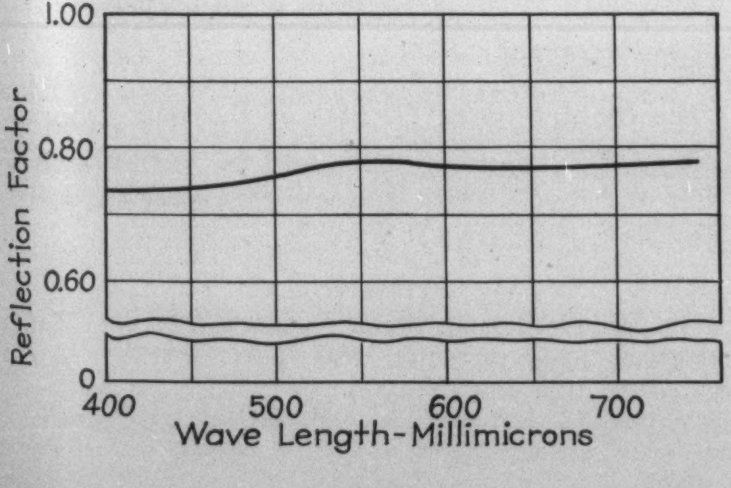
Because of its costliness and low cathode efficiency, rhodium is generally deposited as a very thin coating ("flash plate"), between 0.000001 and 0.000002 in. thick. Naturally, layers of rhodium of this depth tend to be porous and can offer but little protection to underlying base metals. Indeed, accelerated corrosion may result, owing to electrochemical action between the two, rhodium becoming cathodic to the metal higher in the electromotive series. Because of this, special precautions must be taken in the choice of a basis metal. White and yellow golds, as well as platinum and its alloys are suitable for this purpose but are rarely employed this way except in the case of high grade jewelry, as they are too expensive. Silver, while suitable if heavily plated with rhodium, cannot by a typical flash deposit be protected from its eternal enemy, sulphur, unless a deposit of nickel goes on first. Copper and its alloys, white metals, etc., are, for the reason mentioned previously, also unsuited for direct rhodium deposition.

Basis Metal is Nickel

The practical basis metal for rhodium plating is nickel. Nickel resists the acid attack of the rhodium plating solutions; it tends to become passive and thus inhibits the effect of local couples through the pores of the rhodium; it can be deposited in heavy non-porous layers and polished to mirror brightness or deposited directly in bright form.

Rhodium plated costume jewelry is commonly made up of copper, brass or white metal stock, given a short nickel plate and a flash in the rhodium bath. In the cheaper types of jewelry of this kind, the

The high reflectivity of electroplated rhodium is shown by its spectral response curve.



Rhodanized silver pitcher.

Rhodium flashed novelty jewelry.

nickel deposit is often insufficient for protective purposes and such ornaments will show a tendency to tarnish almost immediately. For this reason such trinkets are often given a coating of clear lacquer over the rhodium. Unfortunately this dulls them somewhat and detracts from the beauty of the natural rhodium finish. Better practice is to give the basis metal at least 0.0003 in. of bright nickel, after which it is rhodium plated.

Wear Resistance

Rhodium deposits wear exceptionally well. This, of course, is due to the great hardness of the deposited metal. Layers of 0.000002 in. of rhodium cannot be readily buffed off a basis metal. They must be ground off or stripped in such media as molten cyanide, or by electrolysis with alternating current in hydrochloric acid.

Thin deposits, of the order described, average in cost about 25 cents per sq. ft. at present prices. This enables the manufacturer of novelty jewelry to produce a variety of beautiful metallic ornaments of base metals such as copper, brass and white metal, which in final form look like precious metal and can be sold at relatively low prices. Slightly heavier deposits of rhodium may be found on certain watch parts, instrument parts and optical frames. These are not lacquered. The order of thickness of this type of deposit is around five millionths of an inch.

Technique of Plating Reflectors

Heaviest deposits of rhodium are made on plated search light reflectors. This particular application of rhodium plating is of sufficient interest to merit a rather detailed description of the process.

First, bronze castings of the approximate shape (male), are ground and polished to the calculated parabolic or spherical curvature. These castings are given a light flash of copper, then a slightly heavier coating of mirror-bright nickel. The nickel is then treated with a compound that permits subsequent easy separation of the overlying layers of metal. Now comes a heavy nickel deposit over which is made a very heavy acid copper deposit of about 1/8 to 1/4 in. in thickness. The electroformed metal is then separated from the mold at the nickel-nickel interface.

The electroformed nickel reflecting surface (female) when removed from the mold has a bright mirror finish. Only in the very large reflectors is there a slight "bloom" which requires coloring or polishing off. The formed reflector of nickel with its copper backing is mounted on a bakelite ring and goes to the rhodium plating tank after the non-essential surfaces have been stopped off to prevent waste rhodium deposition.

The rhodium plating tank used for this work in the Bart Laboratories, Belleville, N. J., is the largest of its kind in the world, with a capacity of about 1300 gallons! While most writers on the subject recommend the use of glass or ceramic tanks for rhodium baths, the size of this tank precludes such usage and steel lined with hard rubber is used instead. Similarly, instead of platinum anodes—the orthodox equipment for ordinary rhodium plating—chemically pure lead anodes are used with good results.

Comparatively heavy deposits of rhodium are applied, averaging about $100 worth of rhodium (present prices about $7.00 per gram in solution) on a mirror 5 ft. in diameter. From this figure, it can be estimated, on the assumption that the rhodium is distributed equally over the surface that an average thickness of 0.00003 in. of rhodium is deposited.

These rhodium plated reflectors stand up well under hard usage. They withstand fairly high temperatures without diffusion such as occurs in silvered mirrors and for this reason are finding more and more use in movie projection and spotlight equipment.

Rhodanizing

The process of "Rhodanizing" received a great deal of publicity a year or so ago and it was thought that this method for protecting silverware from tarnishing was the final word and would open up a large market for additional rhodium. Unhappily, as was mentioned previously, a nickel pre-deposit is required for adequate protection and the color of the finished job does not produce the same effect as that of the pure silver beneath. This, combined with the cost of the process, which is somewhat high, put a dent in the demand for this application of rhodium plating.

The trend towards the yellow colors (gold) in modern costume jewelry, has also conspired to limit the use of rhodium plating to a large extent but the white colors are due for a revival and, if the war situation does not raise the price of the metal to untouchable levels, we can expect to see an increase in the use of rhodium plating in the near future.

Acknowledgment

The cooperation of G. Bart of the Bart Laboratories, Belleville, N. J., and Dr. K. Schumpelt of Baker & Co., Newark, N. J., in the preparation of this article, is deeply appreciated.

Reference

*A. W. Hothersall. *Metal Industry, London, Vol.* 48, 1936, page 117.

Annealing Copper for Automobile Radiators

BY EDWIN F. CONE

IN ALL WATER-COOLED gasoline combustion engines, the radiator is a highly essential part. It must be very efficient in cooling the water and at the same time it must be durable, strong and as anti-corrosive as possible. Millions of these so function.

In a lesser degree the prevailing type of car heater—the one using air heated by the hot water of the engine—must be as good a distributor of heat as possible, i.e., it must use a metal that is a good conductor of heat and also anti-corrosive.

In both these cases copper is extensively used.

At the strikingly beautiful new plant of the Harrison Radiator Co., Division of General Motors, Lockport, N. Y., radiators and heaters (and also condensers), in which copper plays the predominant role, are being constantly manufactured.

In the manufacture of the radiators in particular, and to a lesser degree in the case of the heaters, certain metallurgical engineering and heat-treating problems are involved. Through the courtesy of the company, we were permitted to witness the operations in general and to prepare this article, with special emphasis on the heat treatment involved.

Principal Metal is Copper

Briefly, copper being the principal metal used, it must be rolled to the essential gage or thinness, heat treated during the rolling process, stamped or drawn into the various forms or parts, and later assembled or fabricated into the finished product.

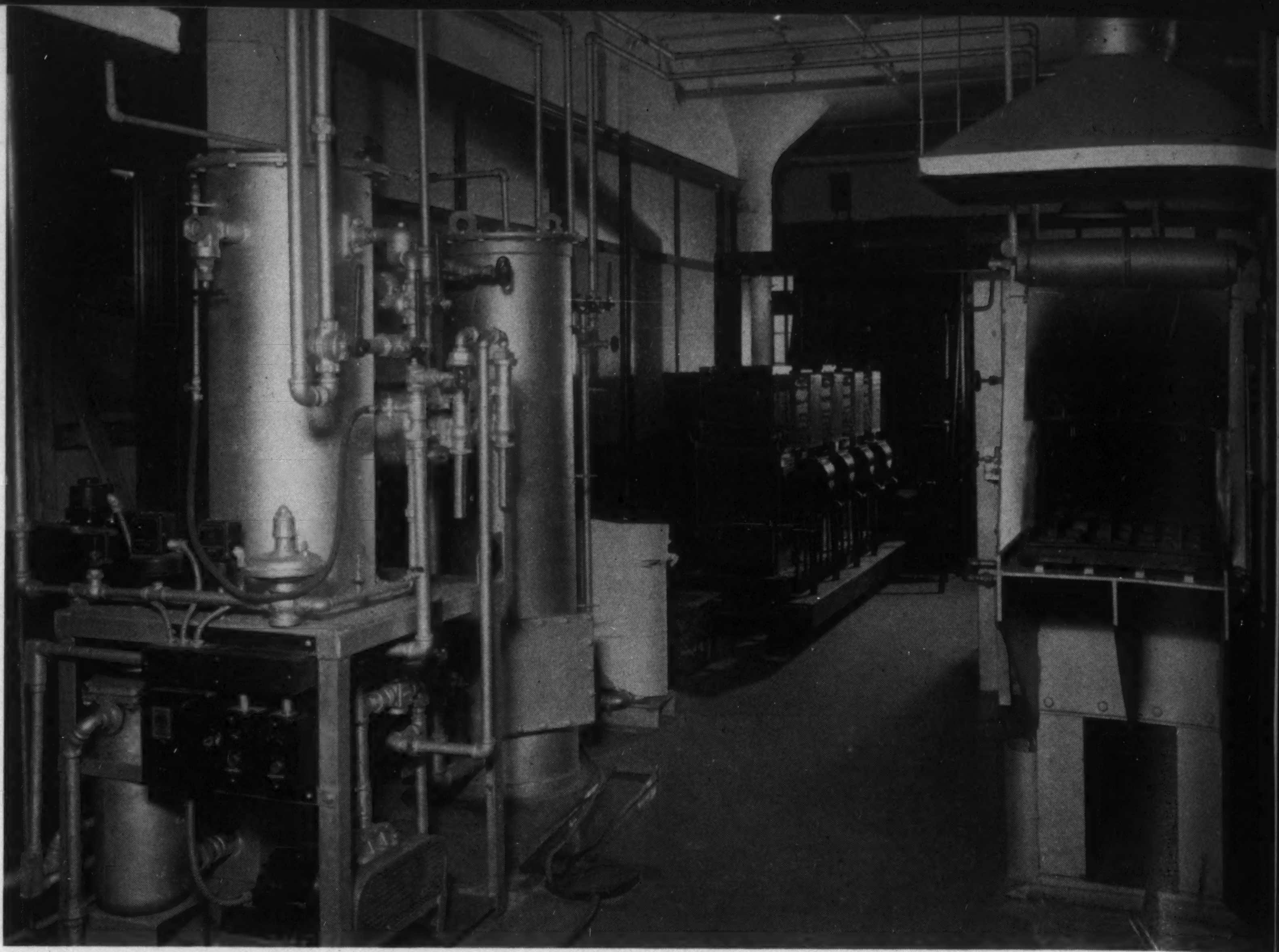
In this discussion we are interested mainly in the heat treating. The copper, mostly electrolytic, is received at the plant in coils. These weigh 125 to 130 lbs. each, and their gage as received is about 0.030 in. They are first put through special roll stands, designed by the company, and cold-rolled with intermittent annealing to a final gage of about 0.005 in. This is the material that is used for the tubes and centers of the automobile radiator.

Because of the work hardening due to cold rolling, and the stresses set up, the copper strip must be annealed—usually between and after certain passes through the rolls as the metal is gradually reduced in gage. For this purpose and to handle the large amount of metal processed, three Westinghouse electric annealing furnaces are used. Each is provided with a controlled atmosphere for the copper must be bright annealed. They are also of the return, recuperative type.

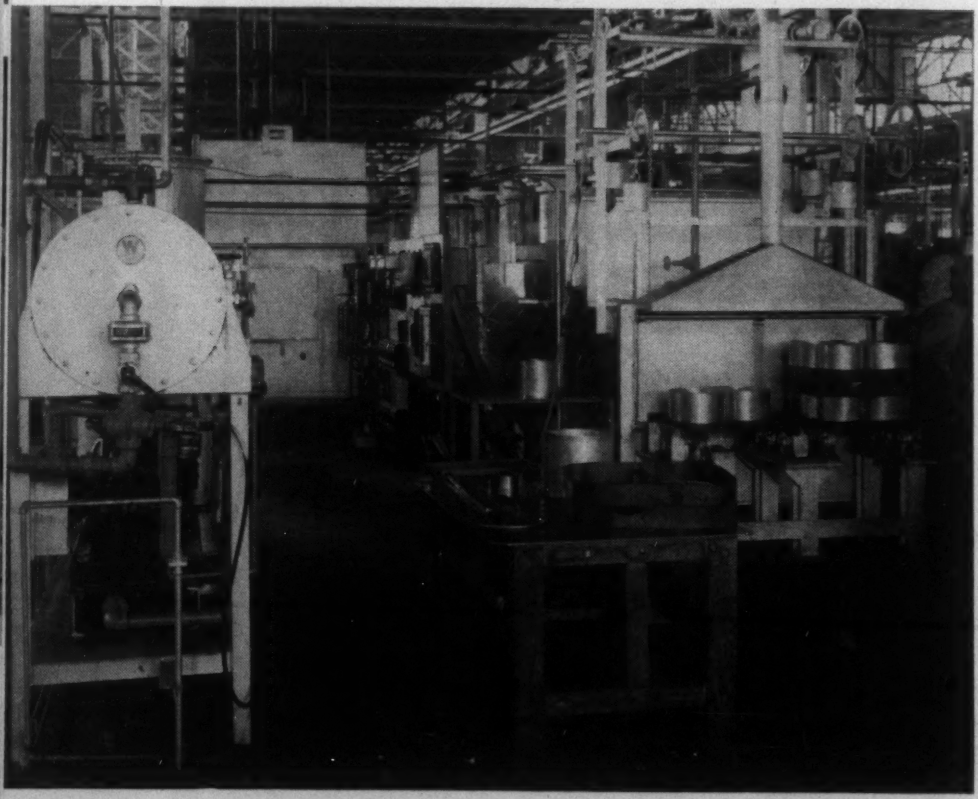
The Heat-Treating Furnaces

One of the furnaces has a maximum temperature range of 1150 deg. F., with the other two at 850 deg. F. The first one, or No. 1, is rated at 130 kw. with 2 zones (the heating) of 96 kw. and 34 kw. respectively. The other two are rated at 125 kw. with the heating zones rated at 91 kw. and 34 kw. respectively. Each furnace is wound for 3-phase, 220 volts. Equipment includes thermocouples, thermal protective fuses, hydraulic operated pusher mechanism, timing mechanism, manually operated doors and so on. The pyrometer equipment includes both indicating and recording control pyrometers. The capacity is 3,000 cu. ft. of controlled atmosphere, filling the entire furnace, though all of this is not used.

Being of the recuperative type, each furnace has parallel compartments or channels—the metal to be treated goes in one end, passes through the recuperator chamber, then into the heating. Here it reaches the end of the furnace where it is pushed across the furnace to start its return journey to the start-



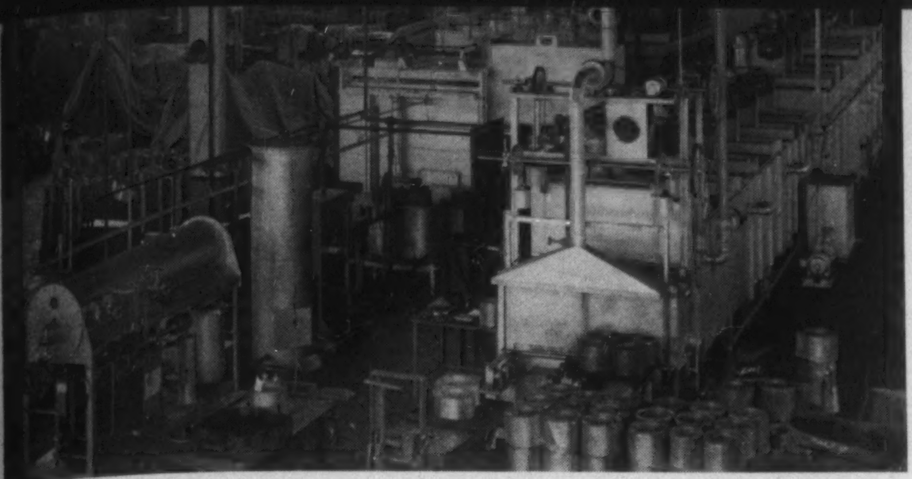
Discharge end on a 60-kw., controlled atmosphere manual pusher type 2100 deg. F. electric brazing furnace showing gas equipment on left and transformers and switches in rear center.



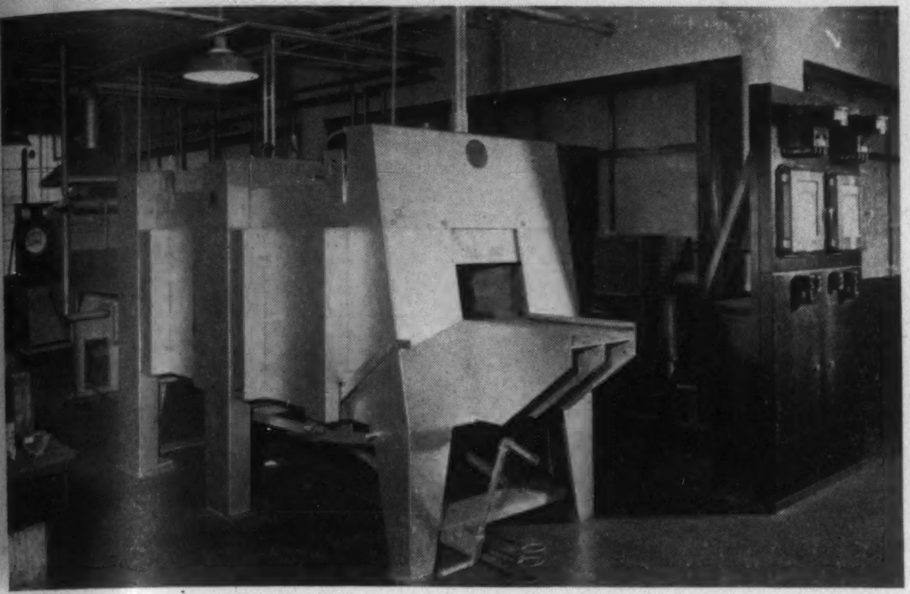
Left: A 130-kw. return recuperative, 1150 deg. F., controlled atmosphere bright annealing furnace, showing gas combustor on left, automatic controls in center, and charge and discharge end at right.

ing end. It continues through the heating or second chamber, then into the recuperator compartment where it transmits some of its heat to the incoming metal. From this point it traverses the cooling chamber. This is separated from the incoming metal by a baffle wall. It finally emerges at the same end next to where it entered. After one batch goes in, another is pushed across the heating chamber or other end of the furnace, and still another batch comes out—all synchronized and automatically regulated.

The large furnace (No. 1) is 68 ft. 5 in. long—the heating chamber 14 ft. 10 in., the recuperative part 10 ft. 1¼ in. and the cooling compartment 31 ft. 4¾ in. The two other lower temperature furnaces are each 84 ft. 10½ in. long subdivided as follows: Heating, 20 ft. 4½ in.; recuperator, 11 ft. 5 in., and cooling, 42 ft. The heating chambers are insulated and the furnace atmosphere is under mod-

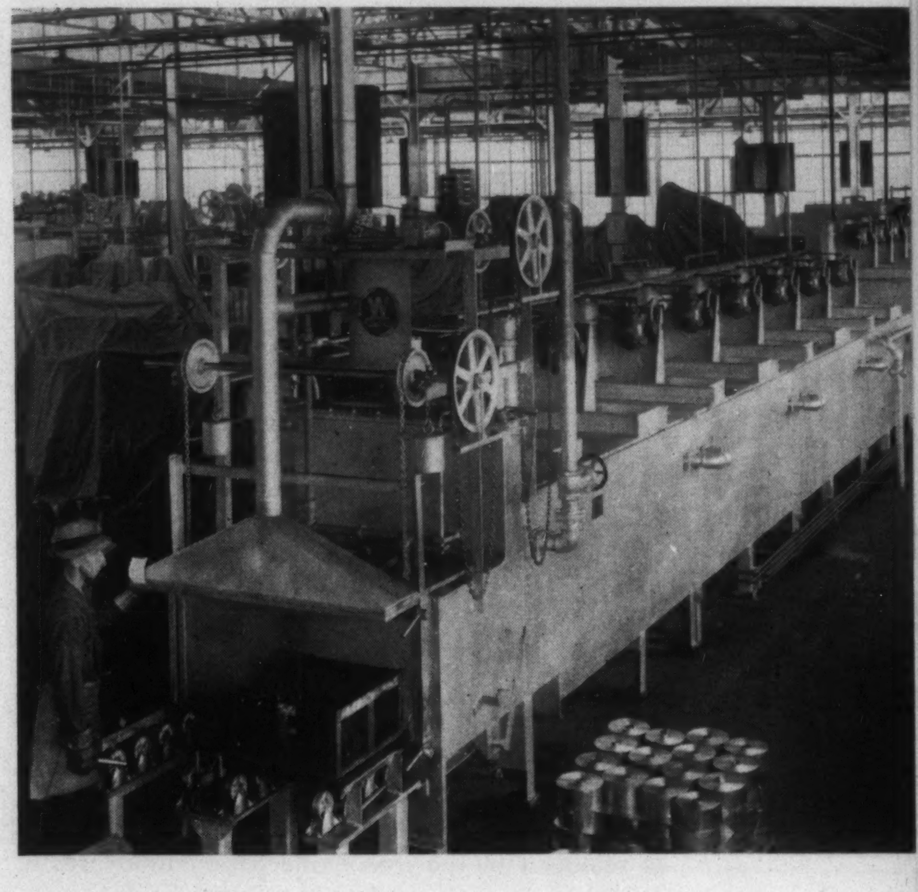


Two return recuperative, controlled atmosphere bright annealing furnaces, showing location of power transformers, a 1150 deg. F. furnace on the right and an 850 deg. F. furnace just to the left, with gas equipment for the 1150 deg. F. furnace in left foreground.



Charging end of 60-kw., controlled atmosphere, manual pusher type, 2100 deg. F., electric brazing furnace, showing indicating and controlling pyrometers and control equipment.

The charge and discharge end of an 850 deg. F. return recuperative controlled atmosphere, bright annealing furnace showing general construction and some of the finished product in the foreground.



erate pressure. The coils of copper are loaded on special trays, made of either cast iron or a special heat-resisting alloy, and used according to conditions.

To insure uniform distribution of the controlled atmosphere, there are 12 fans operating in various parts of the roof. The baffle wall between the cooling chamber and the incoming channel is of sheet steel. The trays containing the copper coils pass on 4 lines of roller rails, two for incoming material and two for the outgoing. These rails are of heat-resisting material in the higher temperature furnace and of cast iron in the other two. The entire operation of charging and discharging the trays is by time clock.

The heating elements are of Ni-Cr ribbon of heavy cross section and are located in the top and bottom of the heating chamber. All control and pyrometer equipment is fully automatic.

The time required for one tray to pass through this furnace is 22 hrs. and 20 min. divided about as follows: 20 min. in the purge chamber, a small compartment at the entering end partitioned from the rest of the furnace; 6 hrs. 20 min. to reach the recuperator; 3 hrs. 20 min. in the recuperator; 6 hrs. in the two portions of the heating chamber; and 6 hrs. and 20 min. in the cooling chamber which is cooled by water coils in the roof. The temperature to which the copper strip is heated depends somewhat on conditions and the use to which it is to be put but averages 900 to 1,000 deg. F.

Apparatus for Controlled Atmosphere

The apparatus for producing the controlled atmosphere in which the copper travels throughout the furnace is interesting. It consists of four main parts: The gas mixing chamber, an iron oxide tower, a refrigerating unit and a charcoal tower. It is designed to produce 3,000 cu. ft. of atmosphere per hour. It must so function as to make an atmosphere low in CO and especially low in H_2 to prevent hydrogen embrittlement of the copper.

An 850 deg. F. return recuperative controlled atmosphere bright annealed furnace showing motor driven fans, control panels and gas equipment.

By means of special apparatus the gas and air—city gas is used—are properly mixed, the air to gas ratio being about 5 to 1. The mixture then passes to the purification equipment where some sulphur is removed in the iron oxide tower, moisture in the refrigerating unit, and final traces of sulphur in the charcoal tower. From this point it enters the annealing furnace.

The actual analysis of the city gas is as follows:

	Per Cent		Per Cent
CO_2	— 1.2	CH_4	— 26.9
O_2	— 0.4	N_2	— 4.0
CO	— 4.5	Illuminants	— 2.6
H_2	— 60.4	S	— 0.02

When this is burned in the generator, the following reactions take place:

$$2\,H_2 + O_2 = 2\,H_2O$$
$$CO_2 = CO_2$$
$$CO + \tfrac{1}{2}\,O_2 = CO_2$$
$$CH_4 + 2\,O_2 = CO_2 + 2\,H_2O$$
$$\text{Ill.} + O_2 = CO_2 + H_2O + H_2S + SO_2$$
$$O_2 = \text{Burned}$$
$$N_2 = N_2$$

Composition of Controlled Atmosphere

The actual gas or controlled atmosphere in the furnace is maintained at about the following composition:

	Per Cent
CO_2	— 9.2
Illuminants	— None
O_2	— None
H_2	— 0.6
CO	— 0.3
N_2	— Balance

To maintain this constant composition, a gas analyzer is used which automatically records the CO and the H_2 present. If the analysis is for any reason thrown out of balance, the analyzer, which is hooked up with the mixing chamber, automatically alters the gas to air ratio: or it can be done by hand.

Emerging from the annealing furnace, the copper strip is as bright as when it went in. Its properties or appearance have not been impaired but rather they have been improved.

The annealed copper is ready for further processing and is used as automobile radiator stock, car heater core stock, or as stock for condensers for refrigerators, heat exchangers, thermostats and so on. Stamping is the main process to which it is subjected in order to prepare the various parts required.

In most of this work, electrolytic copper is used. But Lake copper is also employed—particularly for the thin fins or heat distributors of the car heaters. Here it is found to be stiffer and a little harder—less likely to bend out of shape—due, it is believed, to the presence of small percentages of silver.

Hydrogen, Flakes and Shatter Cracks

A Correlated Abstract • Part I

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Some alloys are so sensitive to hydrogen, that is, to moisture, that one wonders if the melting log should not record whether or not a drop of sweat fell off the melter's nose.

It is not easy to make hydrogen analyses, so about all we know, aside from the various behaviors that are ascribable to hydrogen, is that most metals have some opportunity to pick up hydrogen in processing and that many of them do pick it up in undetermined amounts. More attention needs to be paid to hydrogen. As this review shows, a good deal of attention has already been given it, but not much has percolated through to the shop.

The preparation of this report was carried out as a project of the Research Education Division of Battelle Memorial Institute.—H. W. G.

THE VOLUMINOUS LITERATURE on fissuring phenomena in steel contains a confusion of terms such as: Flakes, Snow Flakes, Silver Streaks, Seams, Hairlines, Shatter Cracks, Quenching Cracks, Longitudinal and Corner Cracks, Forging Bursts, Conchoidal Fracture, Intercrystalline Separation, Transverse Fissures, Primary Grain Boundary Fissures, and others. Careful study of this literature shows that these terms are redundant, that the mass of data contained in the literature needs correlating, and that many strong relationships of these terms and data may be drawn in view of some excellent researches on the functions of hydrogen in steel.

The literature on hydrogen in steel, however, is even more voluminous and confusing, with the result that numerous investigators—possibly dismayed by the formidable task of sorting this literature, have written on fissuring phenomena without benefit of available facts, and are needlessly duplicating work that was done very well years ago. The primary purpose of this study, therefore, has been to examine thoroughly all publications that regard hydrogen in steel, and to describe in detail the important conclusions that may be made after such an exhaustive examination. A more complete bibliography, not here appended, containing 500 selected references has been prepared which completely covers the work on this subject from the first investigation in 1863 through those reported in June, 1939.

(This complete bibliography may be obtained from Bibliofilm Service, care U. S. Department of Agriculture Library, Washington, D. C., by ordering Document 1255, remitting 62 cents for copy in microfilm (read enlarged to full size on reading machines now widely available or hand viewer obtainable for $1.50 from Science Service, Washington, D. C.), or $4.40 for copy in paper photoprints legible without optical aid. The abridged bibliography, appended to this correlated abstract, covers the more important original investigations.)

Among these investigations there is surprisingly clear evidence that several of the commonly observed defects in steel may be directly caused or aggravated by hydrogen contained in the steel. Preliminary experimental work at Battelle Memorial Institute has afforded further proof of the exceptionally great disruptive power of hydrogen in steel.

The premises of the disruptive power of hydrogen in steel, however, are still strongly argued in discussions on fissuring, partly because the operation of a gas in rupturing steel is difficult to picture, and partly because there may be a tendency on the part of some to blame hydrogen wrongly. Therefore, to define more sharply the relations of hydrogen to fissuring, a detailed discussion of hydrogen in steel is followed by a comprehensive review of the type of defect known as "flaking." The relation of hydrogen to other defects is briefly summarized.

Literature on "flaking" has been chosen for careful abstracting mainly because it is important to particularize this discussion, and partly because "flakes" have been widely discussed and are typical of fissuring that is attributable to hydrogen. The formation of shatter cracks in rail steel is of such great economic importance that the discussion has been especially extended also to clarify their origin and to consider methods for their prevention. The bibliography accompanying this article is, to the best of the writers' knowledge, complete through June, 1939, for the subject of flaking in steel. For

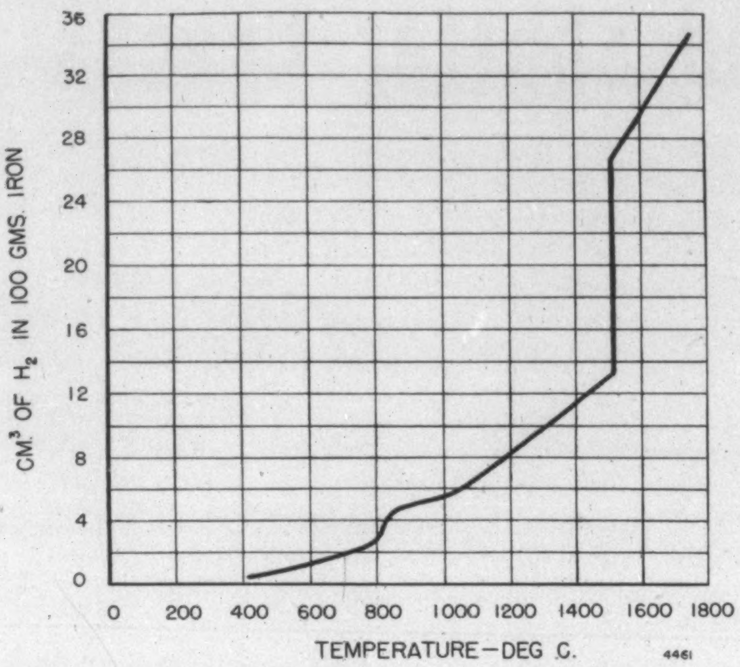
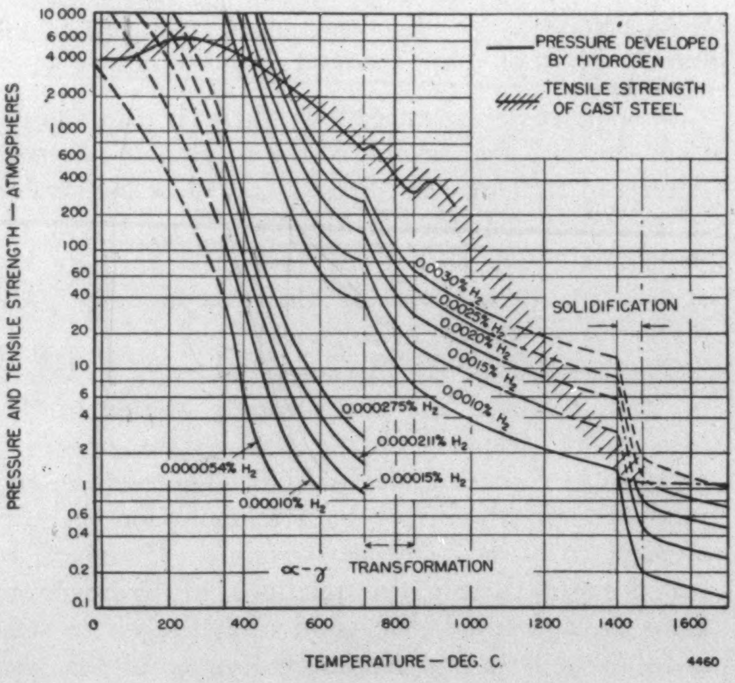


Fig. 1. Solubility of hydrogen in iron P_{H_2} 760 mm. (Sieverts)

Fig. 2. Calculated variation of hydrogen pressure with temperature of ordinary steel (Luckemeyer-Hasse and Schenck)



the best work on shatter cracks in rail steel, the reader is referred to the five Progress Reports of the Rail Investigations Committee of the American Railway Engineering Association at the University of Illinois.

The report aims: (1) To clarify the role played by hydrogen in fissuring phenomena by discussing fundamental studies of the Iron-Hydrogen system; (2) to correlate the literature on the flake-type of fissure; (3) to relate shatter cracks and other defects to hydrogen in the steel; and (4) to discuss methods by which defects caused by hydrogen in steel may be avoided.

The most important original contribution is perhaps the explanation of "reversible occlusion" of hydrogen in steel—an explanation that entails a new conception of the mechanism by which hydrogen embrittles steel, discloses interesting evidence of the nature of the sub-microscopic structure of steel and clarifies a seeming contradiction of theory and data that has remained unexplained throughout many years of investigation.

Part 1: Hydrogen in Steel

Fundamental Aspects

Apparently St. Claire Deville and Troost, in 1863,[1] were the first to observe that hydrogen diffused through solid steel.[2,3] Their discovery started the voluminous, repetitive literature that exists today on hydrogen in steel.

The bulk of this literature regards the embrittling effect of hydrogen dissolved in steel,[154] as the proposal that hydrogen causes fissuring is of rather recent origin. Embrittlement has not been satisfactorily explained, however, and, along with flaking and other defects, may be better understood by first carefully considering some fundamental aspects of the Iron-Hydrogen system. Of great significance, therefore, are the researches of Cailletet[4] in 1868, Müller[5] in 1879, Bellati and Lussana[13] in 1891, Charpy and Bonnerot[21] in 1912, Körber[82] in 1927 and Bardenheuer and Thanheiser[92] in 1928, each of whom showed experimentally that hydrogen could diffuse irreversibly into cavities in steel to form enormous pressures of occluded gas. Bardenheuer and Thanheiser obtained 300 atmospheres pressure of such trapped hydrogen, at which pressure the test was only discontinued because the apparatus was already well past its limit. The phenomenal ability of hydrogen to create enormous pressures within steel has been verified at Battelle Memorial Institute.

Insight into the mechanism of this anomalous formation of high gas pressures was first afforded by the valuable fundamental researches begun in 1907 by Sieverts[18-20, 100, 105, 227] on the variation of the solubility of hydrogen in steel with temperature and pressure. The results, which have recently been carefully checked by Ham[167, 168, 196, 205, 206, 218] established conclusively that hydrogen is dissolved in steel atomically.[211] Specifically, the quantity of hydrogen that will dissolve in steel is directly proportional to the square root of the pressure,[207] which relationship is in accord with the equation:

$$H_2 = 2H$$

and the mass action constant

$$K = \frac{(P_H)^2}{(P_{H_2})}$$

from which

$$P_H \text{ (in the steel)} = K'(P_{H_2})^{1/2}$$

$$P_{H_2} \text{ (outside the steel)} = K''(P_H)^2$$

Deviation from this square root relationship, which has sometimes been observed, is caused by imperfections in the steel specimen. The role of these imperfections forms the basis of this paper.

The variation of solubility with temperature ($P_{H_2} = 760$ mm.) for hydrogen in iron is shown in Fig. 1. It is evident that the sharp decrease in solubility with decreasing temperature will cause a high degree of supersaturation to obtain when steel is cooled from saturation at elevated temperatures. To hold the excess gas, which is atomically dissolved, in solution in the metal, greatly increased pressures of hydrogen outside the metal lattice are required. As the decrease in solubility is considerably more than one thousand-fold between the temperature of liquid steel and room temperature, over a thousand-fold increase in the partial pressure of *atomic* hydrogen would be required to prevent precipitation of hydrogen from a cold steel that had been previously saturated when molten.

At ordinary temperatures hydrogen is so extremely stable in the molecular state that unattainable total pressures of the gas would be necessary to provide this required partial pressure of atomic hydrogen. In addition, increased pressure favors still further the formation of molecular hydrogen, as there is a volume change. Therefore, as the solubility decreases, dissolved hydrogen will diffuse out of the metallic lattice without hindrance; and, when this escape takes place at some discontinuity within the steel, the escaping atoms will immediately recombine to form molecular hydrogen in the discontinuity until (a) the equilibrium pressure (P_{H_2}) is attained, (b) the excess hydrogen is removed from the iron lattice or (c) the metal ruptures.

The rate at which hydrogen diffuses through steel is an important consideration. Researches[207] show that the rate of diffusion decreases logarithmically with decreasing temperature. Steel in the elastic state, where fissuring occurs, then holds its hydrogen with maximum supersaturation and minimum diffusibility, which conditions favor highly localized stresses from the gas. The relation of diffusibility to the well known effects of aging and low-temperature annealing is therefore obvious.

Calculation of Possible Hydrogen Pressures in Steel

The maximum pressure that molecular hydrogen might build in steel is only of theoretical interest, for abundant experimental evidence shows that the strongest steel is easily ruptured by this gas. Luckemeyer-Hasse and Schenck[109] calculated the stresses that could be produced by cooling steels of various hydrogen contents. Applying the mass action law:

$$P_{H_2} = \frac{(P_H)^2}{(K_H)^2}$$

to solubility data (See Fig. 1), these authors derived the curves shown in Fig. 2. It is seen that the pressure developed by only 0.0010 per cent H in steel far exceeds the strength of ordinary steel at 200 deg. C., and that much less gas would be needed, even in the absence of assisting stresses, to cause fissuring at low temperatures.

Luckemeyer-Hasse and Schenck further argued that at low temperatures hydrogen and carbon in the steel react to form methane:

$$C + 2H_2 = CH_4$$

$$K_{CH_4} = \frac{(P_{H_2})^2}{P_{CH_4}}$$

$$P_{CH_4} = \frac{(P_{H_2})^2}{K_{CH_4}} = \frac{(P_H)^4}{(K_H)^4 K_{CH_4}}$$

The values for K_{CH_4} are well known. Taking the value for P_{H_2} from the graph in Fig. 2 at about 530 deg. C. and 0.0010 per cent H, for example:

$$P_{CH_4} = \frac{(P_{H_2})^2}{K_{CH_4}} = \frac{(200)^2}{0.74} = 54{,}000 \text{ atmospheres*}$$

These authors then point out that the pressure of this gas continues to increase with decreasing temperature such that, even with incompleted reactions, the strength of the steel is so far exceeded that rupture is unavoidable.

This reasoning of Luckemeyer-Hasse and Schenck's may not be readily apparent, because the formation of methane ostensibly entails a volume decrease. However, one must bear in mind that the formation of high pressures of molecular hydrogen from atomic hydrogen also involves a volume decrease, and that it is therefore not necessarily the change in volume one way or another by a factor of 2 or 4 that is important, but that methane dissociates less in contact with iron than does molecular hydrogen. An important factor in this case is the diffusion gradient that is immediately established in the direction of the cavity with the first atom of gas that escapes into that cavity. Where the volume of the free-space is small, very little gas is needed to build tremendous local pressures.

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* (The original work in kilograms per square centimeter has been changed to atmospheres without correction.)

The Mechanism of "Irreversible" Diffusion and Occlusion

Although Fig. 1 shows that the commonest source of hydrogen in steel is undoubtedly ordinary absorption at high temperatures, especially during the melting procedure, there are many ways in which large quantities of hydrogen may enter the steel at lower temperatures. In the case of pickling, where iron atoms replace hydrogen atoms at the metal-solution interface, or in the case of electrolysis where steel is cathodic, there is a high concentration of hydrogen already in the atomic state at the steel surface, in which condition the gas is readily dissolved. In the absence of pickling or electrolytic action, other reactions operate to supply nascent, or atomic hydrogen, the commonest example of which is rusting.[12] At high temperatures such reactions are particularly effective. The strong adsorptive forces for hydrogen on iron are attested by the wide commercial use of iron for a catalyst in hydrogenation processes.

With atomic hydrogen on the surface of the steel, a diffusion gradient exists normal to the surface and in the direction of the interior of the steel. In the case of pickling, or of electrolysis, the surface concentration is so unusually high that very large quantities of hydrogen diffuse into the steel.

In the case of steel that is cooled rapidly from saturation at high temperatures, the greatly decreased rate of diffusion precludes general escape of the atomically dissolved gas into the atmosphere. Because the solubility decreases about one thousand-fold from forging temperature to room temperature, a high degree of supersaturation is easy to obtain.[123, 188] In such a supersaturated condition, 999, roughly, out of every 1000 atoms of hydrogen in the steel are pressed to leave. Where may these atoms go?

It has been amply demonstrated that the dissolved hydrogen atom is held interstitially in the iron lattice.[207, 211] To reduce the forces of supersaturation, then, the hydrogen atom may leave the lattice at any discontinuity that is large enough to permit escape from the overstressed field of the host atom. In view of the highly exponential decrease of atomic forces with distance, a large discontinuity should not be necessary. Once it has escaped, the hydrogen atom immediately recombines with another atom[60] to form molecular hydrogen and, as has been discussed, the resulting partial pressure of atomic hydrogen in such discontinuities is so nearly zero that steep, local diffusion gradients are quickly established around each cavity or inclusion. Furthermore, the escape of each atom increases this gradient so that the pressure within the discontinuity is actually self-propagating. The gas will in this manner continue to diffuse into the cavity until equilibrium is reached, or the metal ruptures.

During pickling and electrolysis the continuous supply of gas diffusing into the steel maintains a high concentration that might otherwise be reduced by internal precipitation of molecular hydrogen. Under these conditions the pressure of occluded gas depends principally upon the time allowed for diffusion and upon the volume of the free-space in which the gas collects. In general, therefore, the smaller the discontinuity the more rapidly will the pressure increase, and the magnitude of the pressure is only limited by the strength of the steel.

In the case of steel rapidly cooled from saturation at high temperatures, the supply of atomic hydrogen is limited, and for each size of cavity there is a maximum pressure that may obtain. The absence of an external atmosphere of atomic hydrogen also permits diffusion to the surface. Due to the low rate of diffusion at ordinary temperatures, however, the surface gradient scarcely affects local internal gradients. This effect of diffusion is evidenced in "flaking," which is fully discussed later, by the characteristic central zone of "flakes" that appears with a surrounding flake-free rim.

(To Be Continued)

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Trends in Refractories

Part II - Concluded from April

A Completely Basic Furnace

The performance of basic brick in roof shoulders suggests the elimination of silica brick from the remaining sections of the roof so that a completely basic open-hearth furnace would result. Such a step is very desirable but its realization is not an easy matter. Several years ago a complete sprung roof section using chrome-magnesite brick instead of silica was installed for trial in this country. The life obtained with the basic brick was less than that of silica. From this the conclusion was drawn that a fully basic roof was impractical. Such a conclusion may no longer be warranted in view of recent developments with some of the smaller European furnaces. Heger, Sonnatag, and Leineweher[4] have reported the successful operation of completely basic furnaces of 60-ton capacity. Other Continental steel works have had similar experiences. In England larger furnaces up to 150-ton capacity have been built. The results, however, have not been as uniformly successful with the larger furnaces. This seems to suggest that the difficulties are due to the heavy weight of the larger roofs and the problems which arise as the distance between skewbacks in a sprung arch increases.

Experience in the use of basic arches in copper smelting reverberatory furnaces during recent years sheds some light on the subject. Formerly these furnaces were built with silica arches throughout. Then it was found that the use of basic roof shoulders was economical. Following this, attempts were made to construct a fully basic roof using the conventional sprung construction. Due to the large roof span (25 to 27 ft.) the arches failed due to mechanical causes. Thereupon a suspended basic roof was devised.[5] Unburned magnesite brick of 15-in. thickness were used. The brick were assembled using steel plates about 1/16th in. thick in all the joints. The steel plates oxidized in service and expanded slightly. The oxide combined with the basic refractory and formed a tight, monolithic mass which resisted spalling and other destructive forces. The elimination of the sprung-type of construction solved the mechanical problems of the large furnace. The suspended roof was successful from the very beginning. The first installation gave a roof life of 386 days compared with a former average of 75 days for silica.

J. B. Austin[6] cites a recent report by W. B. Boggs on his experience with basic roofs of this type on a furnace reported to be the world's largest copper smelting reverberatory. By the elimination of the conventional silica roof and substitution of a suspended basic roof in a position 5 ft. higher than the original sprung arch, Boggs was able to increase the furnace charge from 500 tons daily to 1500 tons daily and to decrease the fuel consumption from 15 per cent of the charge weight to 10.4 per cent. The cost of roof refractory per ton of ore smelted was also reduced considerably. Such developments in large reverberatory furnaces may indicate the trend of coming events with basic open-hearth roofs. The present experience with roof shoulders confirms the experience of copper furnaces. The reported failures of full basic roofs on large open-hearth furnaces in England partly confirms the early experiences obtained with copper furnaces. To confirm the final stage, extensive studies are now being made to apply suspended basic roofs to open-hearth furnaces.

Suspended Basic Roofs

L. F. Reinartz[7] reports that suspended basic open-hearth roofs have been installed in Europe and the preliminary results are encouraging. It is claimed the furnaces obtain 150 to 200 deg. higher temperature in the hearth and gave 1000 heats on the

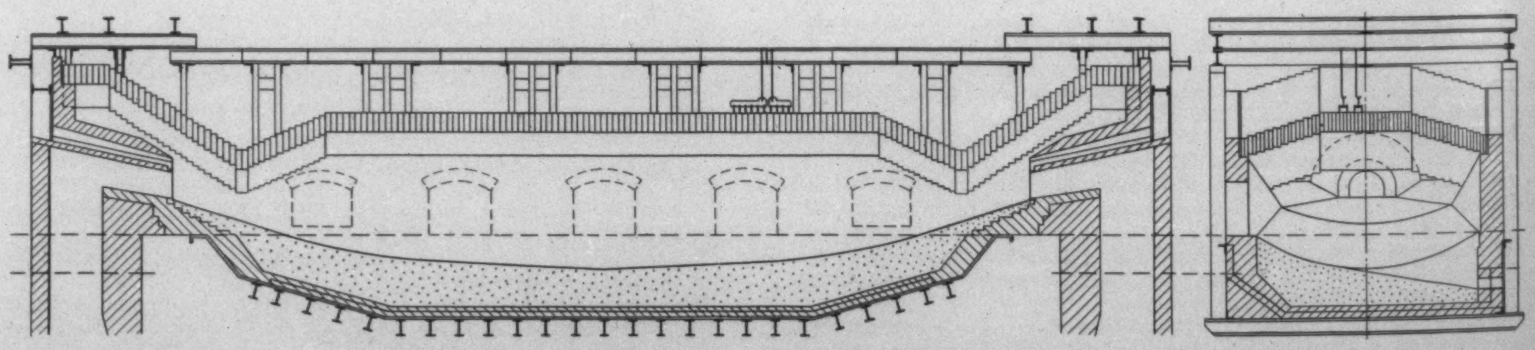

Fig. 3. Open-hearth furnace with suspended basic roof.

for the Basic Open-Hearth Furnace

BY R. P. HEUER
Vice President,
General Refractories Co.,
Philadelphia.

roof. It is now proposed to make some trial installations in this country. A typical layout based on many years' experience with copper furnaces is shown in Fig. 3. The furnace is completely basic and no silica brick are used above the floor level. The buckstays or other suitable supports carry the entire load of the suspended roof. Longitudinal members are joined to the top of the vertical supports and from them a series of cross members span the furnace on approximately 4-ft. centers. The roof brick are hung from these cross members in small groups by means of suspension rods and castings. The roof has a thickness of 15 in. The contour is practically the same as that of the sprung roof previously used. This is done without the use of special shaped brick. The sloping portions of the roof are formed by the use of supporting rods of various length.

A steel plate of 1/32 in. thickness is provided in every joint between the roof brick. For ease in assembly one half of the brick are provided with a steel plate covering each of its four principal faces. The remaining brick are unplated. As the roof is assembled the plated brick and unplated brick are placed in alternate positions so that each joint has a single thickness of metal. The use of bricks which carry the steel plates integrally with them is not necessary, however. Ordinary unplated brick can be used throughout and loose plates can be placed in the joints. With this construction the time and cost of assembly is somewhat greater.

The arrangement for supporting the brick is very flexible. Skewbacks are eliminated and no side thrust is necessary to maintain the arch in position. The roof is free from the shifting compressive forces which are present in a sprung arch. The brick are hung like a pendulum and can move without harm when the refractory expands or contracts. Proper expansion joints, ¾ in. wide, are provided every 3 ft. in both directions. A liberal joint is allowed around the periphery of the roof where it laps into the front, back and end walls. With these ample provisions there is no possibility of strain being set up on the brick due to thermal expansion, or the swelling of the steel plates due to oxidation. No wooden forms are required either in the initial installation or in making replacements. The steel cross members which support the roof form a convenient staging or platform for periodic inspection and for repairs. When repairs or replacements are necessary, small units of brick can be removed through the top of the arch and replaced with new tile. These repairs can be confined to the immediate area that requires replacement with no danger of the adjacent brick falling into the furnace. Hot repairs have been readily made in this way on the copper reverberatory furnaces. This is an important feature of the suspended basic roof as it permits more continuous operation and shortens the time lost for roof repairs.

Since the maximum temperature of the open-hearth roof exceeds the copper furnace roof by 400 deg. F. it is necessary to use unburned chrome-magnesite brick instead of the unburned magnesite brick used for copper smelting. This is advantageous since the cost of the brick is lower and the resistance to spalling greater. The thermal conductivity is much lower than magnesite as shown in Fig. 4. Indeed the unburned chrome-magnesite brick have a thermal conductivity less than silica brick at temperatures above 740 deg. F. It is interesting to note that the conductivity of chrome-magnesite brick falls as the temperature rises while the reverse is true with silica.

Iron Oxide Attack

In substituting chrome-magnesite brick, due consideration of the problem of iron oxide attack on these brick is necessary. Chesters[8] has described the premature failure of chrome-magnesite brick in open-hearth sidewalls as being due to magnetite deposited on the brick which enters the lattice of the chromite spinels, and causes a crystalline growth with final disintegration of the hot face of the brick. Magnesite brick do not disintegrate in this way. Iron oxides flux magnesite slightly at high temperatures and cause shrinkage of the brick instead of expansion. The brick shown in Fig. 5 illustrate the typical differences between a magnesite brick and a chrome-magnesite brick which is susceptible to iron-oxide swelling. These brick were heated simultaneously to 3000 deg. F. inside a test furnace and excessive amounts of iron oxide were applied to the top face of each brick. The magnesite brick on the left of the photo shrank somewhat and its surfaces are covered with a fused slag. The chrome-magnesite brick in the center absorbed the iron oxide. Its surfaces are dry and free of slag. The iron-oxide absorption has caused the end of the brick to expand more than ½ in. in width. Large cracks appear in the body of the brick and the disintegration is evident. Fortunately, it is possible to make chrome-magnesite brick which are less sensitive to iron oxide

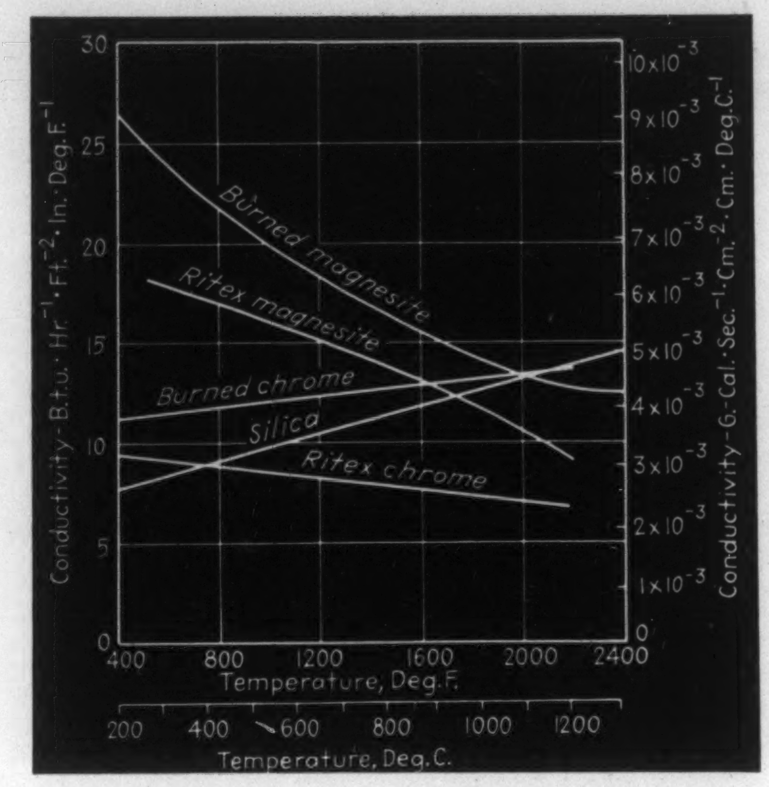

Fig. 4. Thermal conductivity of basic open-hearth refractories.

attack than the brick just described. Such a brick is shown on the right of the photo. It is free from the excessive shrinkage of the magnesite brick and the disintegration of the usual chrome-magnesite brick. The iron oxide tends to remain on the surface of the brick forming a liquid slag rather than penetrating the brick to cause expansion. Of course, the test conditions are worse than would be experienced in an open-hearth roof because the test brick are heated on all sides and the amount of iron oxide is purposely excessive.

In order to take full advantage of the economies possible by the use of suspended basic open-hearth roofs it is necessary to consider changes in other parts of the furnace. Some of the European furnaces operate with their maximum roof temperatures about 200 deg. F. greater for basic roofs than for silica. Shorter time per heat and less fuel per ton of ingots is claimed for such operation. In order to obtain these higher temperatures, combustion problems must be worked out. Driven fuel seems desirable. Temperatures must be carefully controlled for the roof, the ends of the furnace and the regenerators. With higher roof temperatures the exit gases from the furnace itself are hotter. The regenerator system must be capable of recovering this heat and returning it to the furnace at a correspondingly higher temperature. In many furnaces the use of higher temperature on the top courses of the checker brick will cause rapid failure there. Fig. 6 shows the effect of checker dust on clay and silica checker brick heated to 2650 deg. F. in a laboratory furnace.

For this test a 1/4-in. layer of dust comprising 90 per cent Fe_2O_3, 5 per cent CaO, 5 per cent Al_2O_3 was troweled on the 9 x 4 1/2-in. face of the test brick. The brick were then dried and fired to 2650 deg. F. for 5 hrs. During the heating the oxide layers shrank and cracked so that the surface of the brick was not completely covered. At the maximum temperature the oxides caused rapid destruction of the clay and silica brick where they were in contact with them. In order to avoid this the top courses of the checker brick should not exceed 2450 deg. F. If it is necessary to exceed this temperature, unburned magnesite brick can be used to avoid the iron oxide attack. Fig. 6 shows such a brick which was tested simultaneously with the clay and silica brick. The oxide layer has shrunk and sintered together but the magnesite is unaffected. Despite the resistance of the brick it is questionable whether the operation of checkers at higher temperature would prove generally desirable. Actual trials have shown that the brick will not fail but the dust deposits sinter together strongly at the high temperatures and cannot be cleaned from the brick. The difficulty with hotter checkers could be overcome by the use of basic brick in the ends and downtakes of the furnace to increase the heat absorbing power of these parts. Basic brick weigh about 50 per cent more than silica and each brick has a corresponding higher heat capacity. If magnesite brick are used the regenerative capacity is further increased due to their higher thermal conductivity. For best results the ends and downtakes must be large enough to take care of the additional temperatures with sufficient margin of safety.

One of the most desirable objectives of basic roof construction is to reduce the lost time on the furnace due to repairs and rebuilds. The basic furnace campaign will be longer. The other parts of the furnace must also be improved to give longer life. Sloping backwalls will be necessary to eliminate lost time due to backwall repairs. Archless-frame frontwalls or other types of construction which utilize basic brick will minimize frontwall repairs. Endwalls and downtakes will last longer if built of basic brick instead of silica. Bottom construction and maintenance will be simplified by taking advantage of the higher temperatures available for burning in the bottom materials. Less open-hearth slag will be needed. The brick bottom will preferably be constructed of chrome-magnesite brick since these brick will be able to stand the higher burning-in temperatures better than ordinary chrome brick. The first layers of grain magnesite will be burned in place on the brick using some open-hearth slag addition but not in excess of 15 per cent. Subsequent layers will have diminishing amounts of slag and the final layers would require little or no slag addition.

Economy of Basic Roof

The economy of a basic open-hearth roof is at present an undetermined quantity. Sufficient data are not available to justify a satisfactory conclusion and much development work still remains to be done. The greatest difficulty to be overcome is the high rebuilding cost of the basic roof which will probably range up to five times that of the conventional silica roof. The basic roof will last longer than silica but there is now no assurance that it will last as much longer than silica as the rebuilding cost is greater than silica. In order to be practical it may not be necessary that the longer life be exactly equivalent to the higher replacement cost. It is quite possible that the refractory costs for the roof might rise 10 to 15c per ton of ingots and still be economical. If it is possible to reduce the time lost on the furnace for repairs and replacements and to increase the rate of melting with corresponding reductions in fuel and other charges, the increased refractory cost would not be prohibitive. The solution of the basic roof problem will not be obtained in the first installation. The subject merits considerable study and expenditure. If the first trials are within striking distance of the present silica roof costs their continuation would be justified since experience in operating such roofs on a large scale would undoubtedly lead the way to important developments.

A basic roof for a basic open-hearth furnace is a logical combination. Recent developments which have been made in refractories and in other metallurgical furnaces warrant serious consideration of the basic roof problem in the steel industry.

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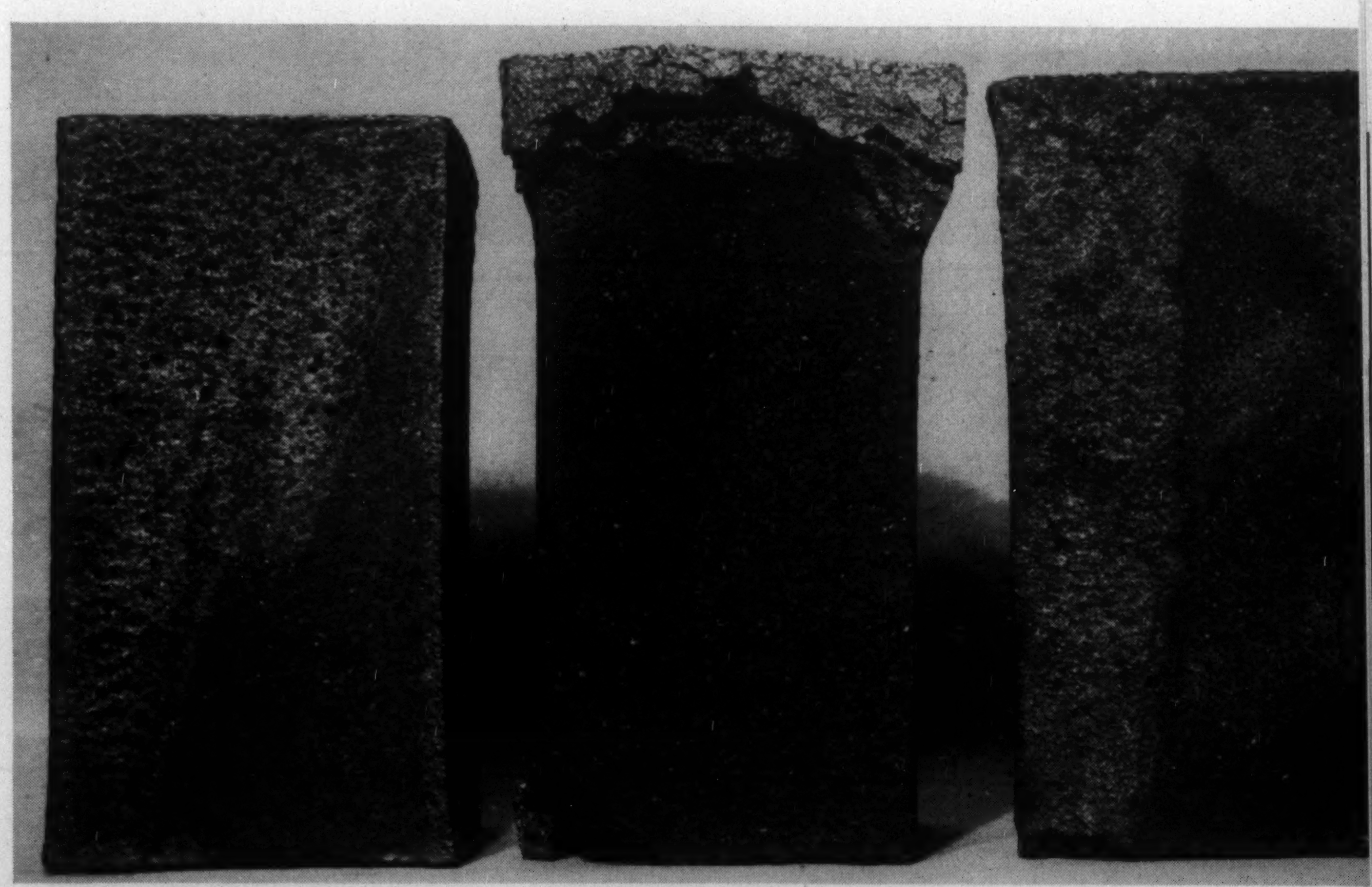

Fig. 5. Basic brick which have been subjected to iron oxide bursting action at 3000 deg. F. Left, a magnesite brick; center, chrome - magnesite of low bursting resistance; right, improved chrome-magnesite brick with good bursting resistance.

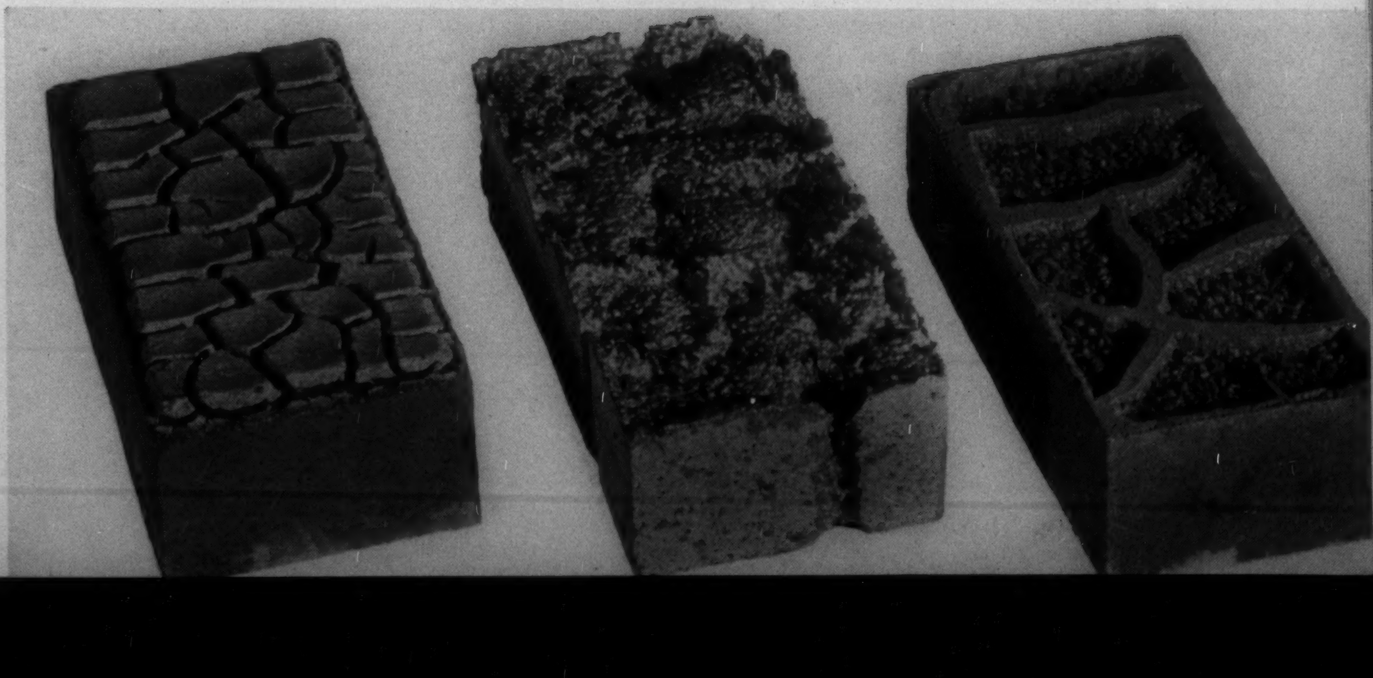

Fig. 6. Effect of open-hearth dust on checker brick at 2650 deg. F. Left, unburned magnesite brick; center, first quality fireclay brick; right, silica brick.

Editorial

(Continued from Page A21)

slide by the canoe, in now and then thrilling to the arch of a fly rod connected to a leaping small-mouth, or in watching the waving plume of a setter's tail as he shuttles over promising pheasant cover, traffic in the lakes and fields would be too congested. Nature knew what she was about when she made folks different.—H. W. G.

Forty Plus

For a number of years and particularly during the depression there has been a strong feeling against the employment of a man over 40—a few companies have adopted the policy of not employing such men. Does "life begin at 40" or does it end? For many capable and worthy men, it has virtually ended in recent years.

In one or two cities of the country there have been organized, within the last year or so, small groups known as "the Forty Plus Clubs." Membership in these clubs is confined to men 40 or over who have achieved some distinction and success in business, who have earned not less than $4000 per year, but who are now unemployed. Each member devotes two days a week to the club, investigating openings for other members than themselves and furthering the interests of the organization. No fees are charged.

Our attention was called recently to the results of the work of the New York club. It was founded on Jan. 19, 1939, with 27 members. It now has (March) 139 members and 165 alumni, who are men who have found employment through connection with the club. At one time it had 241 members and only 61 alumni.

Such work is highly to be commended. Many men in the "40 plus" classification are capable, efficient and highly trained—men with experience and a background. In New York, many engineers, metallurgical and others, executives and business men have found a chance to prove their worth, to demonstrate that "young blood" is not the only thing to be desired, and to gain a new lease on life. —E. F. C.

We cannot suppress a strong tinge of regret that henceforth all production data of the American Iron and Steel Institute are to be published in net instead of gross tons. We like to be able to compare readily our own data with that of other countries and with that of our own Government reports. The British use the gross ton and most continental countries employ the metric—and this differs only 36 pounds from the former. Thus comparisons were easy. Just because a few American steel companies use the net ton seems an unjustified reason for so altering the large mass of accumulated data and thereby imposing a decided inconvenience on many interested in statistics, both domestic and foreign. —E. F. C.

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letters TO THE EDITOR

High Purity Lead and Zinc

To the Editor: Some people have the erroneous idea that zinc was the first common metal commercially available of 99.99 per cent purity, although it has been on the market for only about 10 years.

Lead of 99.99 per cent purity has been sold by my company in commercial quantities for at least the last 35 years and yet we do not claim to be the first producers.

Actually, there is a need for great quantities of high purity zinc, whereas this high purity lead is not apparently needed in amounts representing more than a small percentage of the total amount of lead sold each year. Such zinc is used mostly in the die casting industry, while such lead is used particularly for molten baths for hardening and tempering steel.

Both the high purity lead and zinc can be purchased at moderate prices.

George O. Hiers.

National Lead Co., Brooklyn, N. Y.

Electrolytic Cleaning

To the Editor: I was much interested in your new "Metallurgical Engineering Digest" department, and especially in the digest entitled "Electrolytic Cleaning" on page MA 23 of the January issue. This digest of an article by Sacchi in a German magazine gives much space to the process of electrolytic cleaning combined with simultaneous deposition of a copper coating, and the statement is made that such practice is a "relatively recent development."

Someone owes Dr. Oliver P. Watts an apology, for he described this very process in much detail 25 years ago in a paper "Cleaning and Plating in the Same Solution," *Trans. Electrochemical Soc.*, Vol. 27, 1915, p. 141. Comparison of Sacchi's process with Watts' shows the former to offer no really new features.

A most important point has been overlooked by Sacchi or by your abstractor. Dirt, grease, oils and other substances removed in an electrocleaner from articles being treated have the bad habit of acquiring an electric charge; they may become colloidal and will be carried over to the cathode with the result that staining, roughness and poor adhesion are obtained.

George B. Hogaboom

New Britain, Conn.